Wind Power Today

Wind Energy Research Highlights

- Wind Energy—Serving National Energy Needs
- Developing Low Wind Speed Technologies
- Bringing the Technologies to Market
- Exploring New Markets
- DOE Wind Energy Research

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Wind and Hydropower Technologies Program

Message from the Assistant Secretary

"Bringing you a prosperous future where energy is clean, abundant, reliable and affordable…"

The Office of Energy Efficiency and Renewable Energy provides national leadership to revolutionize energy efficiency and renewable energy technologies, to leapfrog the status quo, and to pursue dramatic environmental benefits.

The Department of Energy Wind and Hydropower Technologies Program is a critical element of our overall effort. This aggressive, peer reviewed, competitive R&D program and supporting activities continue to lead the national investment to harvest America's vast, domestic wind resources. In the coming years, the program will continue to deliver on this investment by increasing the competitiveness of wind generation systems to capture even greater wind resources across the country.

By working in partnership with states, communities, and the private sector, we will ensure our program's success and lead our nation to a stronger economy, a cleaner environment, and a more secure energy future.

David K. Garman
Assistant Secretary
Energy Efficiency and Renewable Energy

Wind & Hydropower Technologies Program — Harnessing America's abundant natural resources for clean power generation.

Cover photo: GE Wind Energy's 1.5 MW wind turbines off the coast of Sweden.

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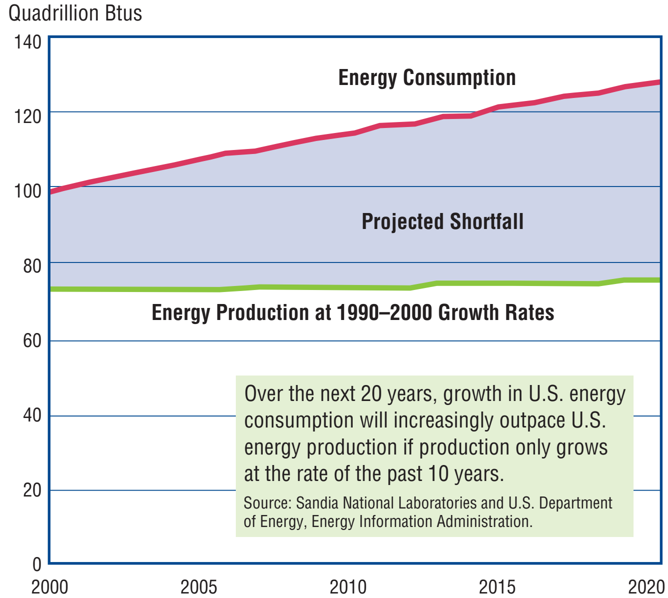
2002 Wind Energy Research Highlights

WIND ENERGY — SERVING NATIONAL ENERGY NEEDS

Growth in U.S. Energy Consumption Is Outpacing Production



Rising fuel prices, energy shortages, unstable foreign fuel supplies, and environmental impacts are a few of the energy challenges that may pose a threat to our Nation's economy, our standard of living, and our National security during the 21st century.

According to the National Energy Policy (NEP) published by the National Energy Policy Development Group in 2001, these challenges stem from an energy supply/demand imbalance—our Nation consumes more energy than it produces. To meet the energy imbalance challenge, the NEP calls on the Nation to draw on its technological ingenuity and expertise to increase our energy production through research, development, and deployment of domestic, dependable, affordable, and environmentally responsible energy technologies that modernize our energy infrastructure.

In 2002, the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) developed a strategic plan to support the NEP. The EERE mission is to strengthen America's energy security, environmental quality, and economic vitality through public-private partnerships that:

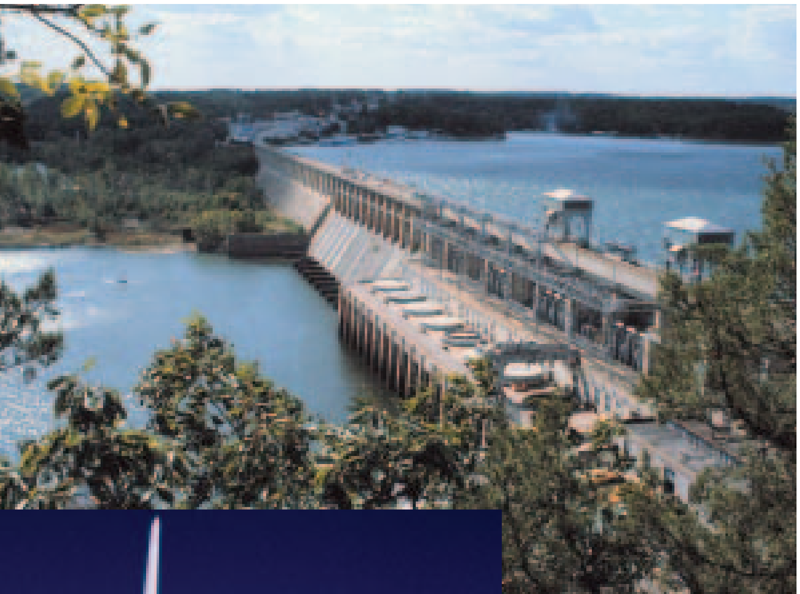
- Enhance energy efficiency and productivity
- Bring clean, reliable, and affordable energy production and delivery technologies to the marketplace
- Make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life.

Strategic goals of EERE include:

- Dramatically reduce, or even end, dependence on foreign oil
- Increase the viability and deployment of renewable energy technologies
- Conduct field tests and facilitate market adoption of renewable energy technologies by partnering with private companies
- Increase the reliability and efficiency of electricity generation, delivery, and use
- Increase the use of renewable energy by promoting renewable technologies on Federal sites.

Meeting Our Nation's Energy Mission

In most cases, the members of the private sector do not have the capital required to invest in high-risk, high-value research and development that is critical to the development of our Nation's energy resources. One of the



DOE's Wind and Hydropower Technologies Program conducts research to advance wind-turbine designs that can operate economically in lower wind resource areas and develop more environmentally friendly technologies to maintain the Nation's existing hydropower capacity.

Wind energy researchers work with industry partners to develop advanced wind energy technologies.

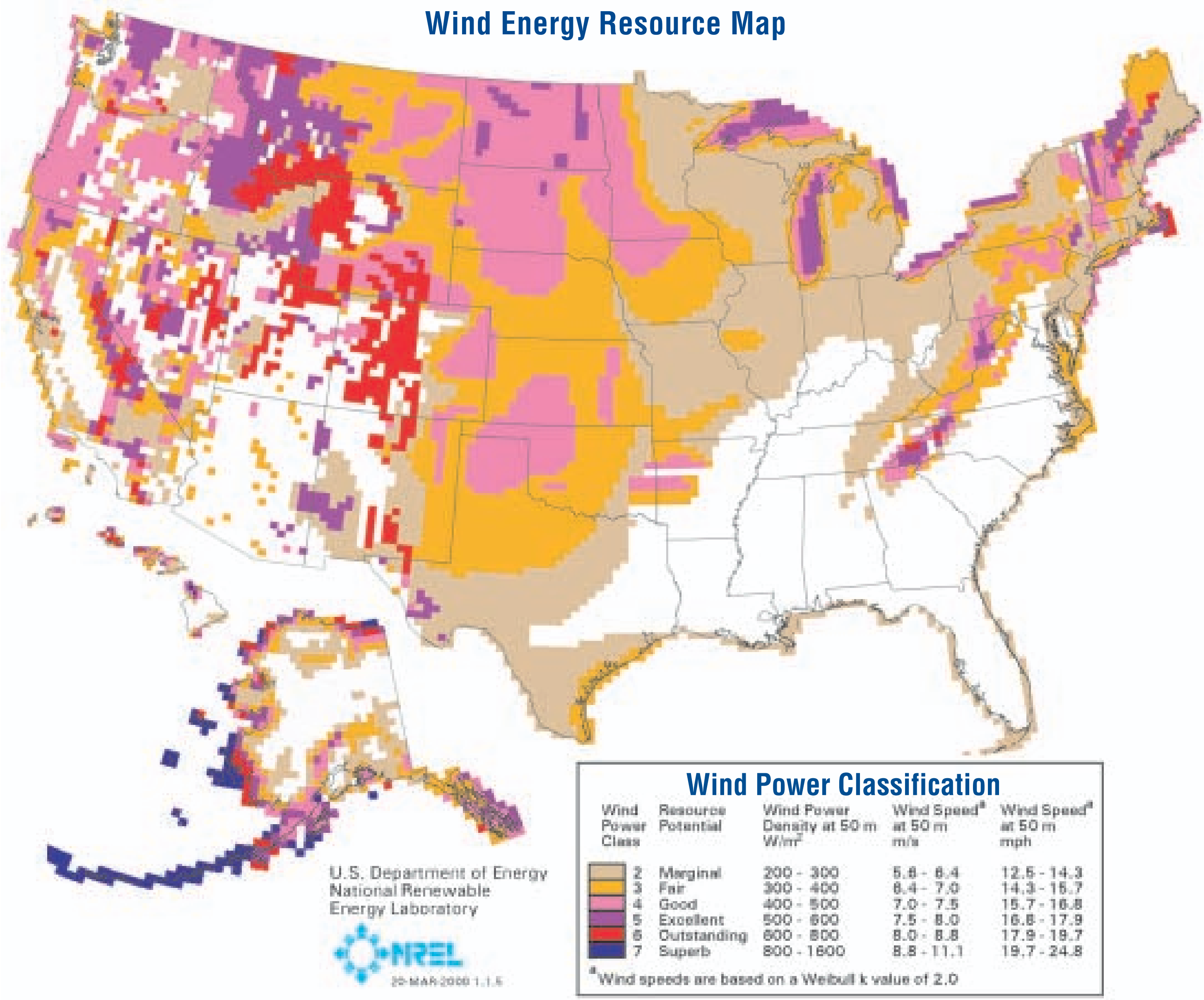
11 programs that EERE established to meet its research and development goals is the Wind and Hydropower Technologies Program. The wind energy research currently strives to meet EERE's mission by conducting research and development to advance wind turbine designs that can operate economically in lower wind resource areas.

Our Nation's wind resources can provide an inexhaustible domestic source of energy. By developing those wind resources, we can help balance the energy scales, stimulate rural economic development, and displace harmful emissions created by traditional fuel sources.

Wind energy has become the fastest-growing form of energy generation in the United States and around the world. According to the American Wind Energy Association, a record 6,868 megawatts (MW) of new wind power capacity was installed worldwide in 2002, bringing the total global capacity to more than 31,000 MW. By the end of 2002, our Nation's wind energy capacity had grown to almost 4,700 MW, providing enough electricity to power almost 3 million average homes. More than 400 MW of capacity were added in 2002, and 27 states now host utility-scale wind power development. This industry growth can be attributed to a greatly reduced cost of production (from 80 cents [current dollars] per kilowatt-hour [kWh] in 1980 to 4 cents per kWh in 2002), an increased demand for clean diverse sources of energy, and state and Federal incentives designed to stimulate the market. Although last year's growth rate of 10% was much lower than the 66% growth rate in 2001, the average U.S. growth rate for the past 5 years is 24%. This growth is tapping only a small portion of our Nation's wind resources.

Since 1980, wind energy researchers have worked with industry partners to develop advanced wind energy technologies that are cost effective in high wind resource (Class 6) areas with an annual wind speed of 6.7 meters per second (m/s) at a height of 10 m (15 miles per hour at a height of 33 feet). As the industry continues to grow, the number of outstanding Class 6 wind resource sites with easy access to transmission lines will dwindle, leaving only hard-to-access high wind speed sites and lower wind speed sites. The full development of accessible Class 6 sites may cause wind energy growth to plateau in the near future unless improvements in technology can make lower wind speed sites more cost effective.

Wind Energy Resource Map



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

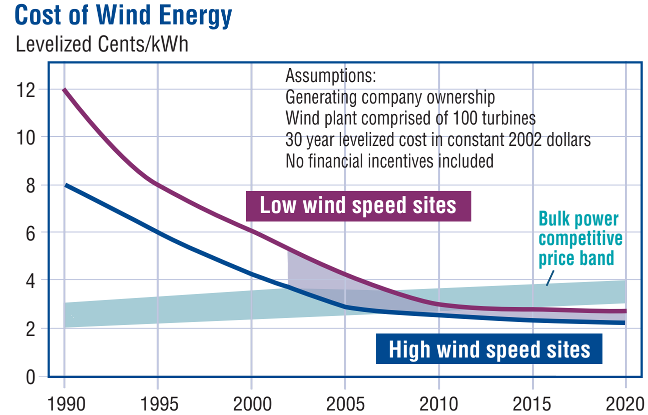
[a]Wind speeds are based on a Weibull k value of 2.0

Ensuring Industry Growth

In addition to helping industry develop low wind speed technologies, DOE's wind energy researchers work to resolve issues involving utility integration that may impede deployment and stimulate industry growth by increasing stakeholder knowledge and public awareness through education and outreach efforts.

To solve wind integration issues, DOE researchers work with industry to gain a better understanding of how the intermittent supply from wind can be used to provide a reliable power source and find ways to make wind plants more productive. By collecting data on current projects and running simulations, researchers can provide utility members with the type of information that will increase their confidence in the reliability of wind energy projects.

Cost of Wind Energy



The phenomenal growth experienced by the wind energy over the past decade can be attributed to a greatly reduced cost of energy.

As the wind energy industry continues to grow, the number of excellent wind resource sites with easy access to transmission lines will dwindle.

DOE undertakes cost-shared industry- and state-based outreach and technical assistance to increase public awareness of wind energy through its Wind Powering America (WPA) activity. Members of the WPA team work to form strategic partnerships on state and regional levels and to provide technical support and distribute informational materials about utility-scale development and small wind electric systems to utilities, rural cooperatives, Federal property managers, rural landowners, Native Americans, and the general public.

In the past decade, wind energy has become a valuable and dependable source of electricity worldwide. As a renewable, domestic resource, wind energy is poised to become our least expensive form of bulk electricity generation. Although the promise of wind energy is immense, continued industry growth rests heavily on sustaining aggressive research, development, and support programs. ◆

GE Wind Energy's 1.5 MW wind turbines at the Klondike Wind Farm near Klondike, Oregon, contribute 24 MW of wind energy capacity to the Nation's total.

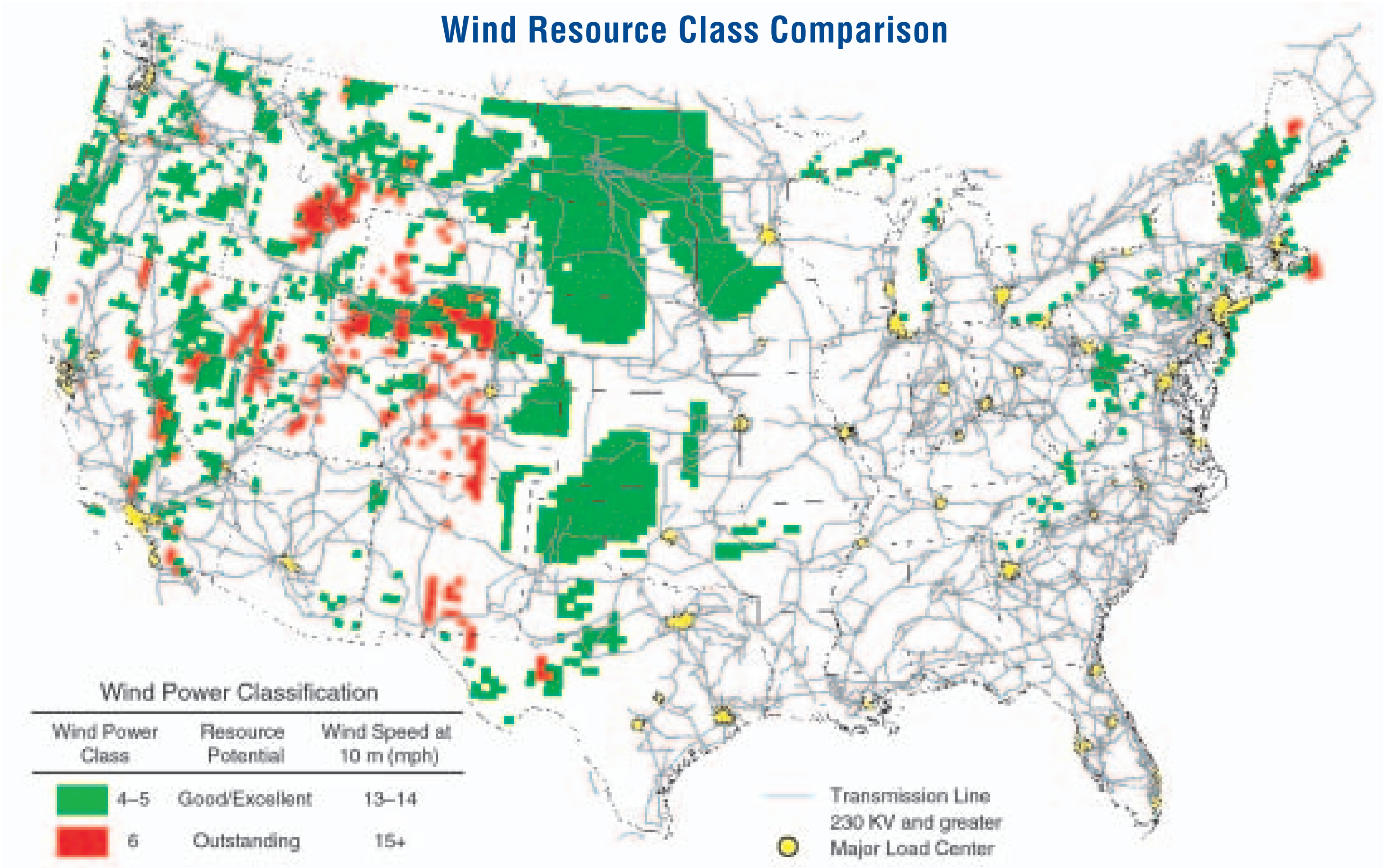
DEVELOPING LOW WIND SPEED TECHNOLOGIES

The Need for Low Speed

The winds that blow across the Great Plains are capable of generating more energy than our Nation currently uses. To tap that vast energy resource and help balance our Nation's energy scales between consumption and production, we need to find ways to develop that resource to its full potential.

DOE's wind energy researchers have worked with industry partners for two decades developing advanced wind turbines designed to produce low-cost electricity in high wind, Class 6, resource areas where the average annual wind speed is 6.7 meters per second (m/s) at a height of 10 m (15 miles per hour [mph] at a height of 33 ft.). Our current wind capacity of almost 4700 megawatts (MW) is produced by wind farms located in some of our Nation's best wind resource areas. However, as the wind energy industry continues to grow, the outstanding high wind resource sites with easy access to transmission lines will dwindle, leaving only hard-to-access high wind speed sites and the lower wind speed areas. The full development of accessible high wind sites may cause wind energy growth to plateau in the near future unless improvements in technology can make lower wind speed sites more cost effective.

Many of America's low wind speed or Class 4 wind sites, where the average annual wind speed is 5.8 m/s at a height of 10 m (13 mph at a height of 33 ft), are located in America's heartland on farms, ranches, and in rural communities from central and northern Texas to the Canadian border. Class 4 sites are also found along many coastal areas, around the Great Lakes, and along shallow coastal areas of the eastern United States.



The ability to develop Class 4 wind resource areas will ensure continued industry growth and further reductions in cost of wind energy production.

In addition to covering a larger portion of the U.S. landmass, Class 4 sites are also significantly closer to the major load centers than Class 6 sites. The current average distance between Class 6 resource areas and the 50 largest load centers is nearly 500 miles (800 km). The average distance for most Class 4 sites is about 100 miles. If Class 4 wind resource areas were developed to their full potential, transmission costs for wind energy could be greatly reduced, and total land area available for wind development would increase 20 times. Developing this rich renewable resource, through utility-scale and small wind electric system applications, will also provide economic and environmental benefits. Wind farms provide additional income for rural landowners, and needed jobs and tax revenues to rural communities, while providing a low-cost option to mitigate emissions from traditional electricity generation plants.

Although wind energy technologies have come a long way over the past 20 years, reducing production costs from 80 cents per kilowatt-hour (kWh) (current dollars) to 4 to 6 cents per kWh, the technology must become even more efficient to produce cost-effective electricity in the lower wind speed areas. By building on the stepping stones provided by past research efforts conducted under the WindPACT and the Next Generation Turbine Projects, researchers estimate that they can reduce the cost of energy by an additional 30% to 50%.

The U.S. Department of Energy (DOE) has a long successful history of providing its industry partners with cost-shared technical support in the form of design review and analysis; dynamometer, compont, and field testing services; and field verification and certification services for wind turbines that range in size from 400 watts to 1.5 MW. This past work led to the development of prototypes that evolved into commercially produced wind turbines capable of competing with traditional forms of energy generation.

The goal of DOE's current low wind speed research and development is to continue to work with its industry partners to develop multimegawatt turbines that produce electricity for $0.03/kWh at Class 4 sites by 2012.

To achieve that goal, researchers need to find ways to optimize the use of materials and machinery and to fine-tune wind turbine structures to withstand the loads unique to the lower wind speed sites. Technology improvements need to be made in three principal areas:

1. Turbine rotor diameters must be larger to harvest the lower-energy winds from a larger inflow area without increasing the cost of the rotor.

2. Towers must be taller to take advantage of the increasing wind speed at greater heights. Again, the approach taken for these towers needs to be less costly than traditional approaches if the benefit from increased energy capture is to exceed increased tower costs.
3. Generation equipment and power electronics must be more efficient to accommodate sustained light wind operation at lower power levels without increasing electrical system costs.

Building Multimegawatt Turbines

To become more efficient and cost effective, wind turbines have grown in size. In 1997, the average installed turbines were producing 600 kW to 750 kW — enough electricity to power approximately 200 to 300 average homes. Today, turbine research and development is focusing on multimegawatt machines that can produce enough electricity to power two to three times that number of homes. As turbines grow in size, they require more materials and are more difficult to transport and install. The challenge for industry is to keep the cost of producing the larger turbines down. DOE's National Renewable Energy Laboratory (NREL) and Sandia National Laboratories are conducting research in the areas of basic science and applied research that will help industry overcome current technology limitations and enhance the individual components to achieve cost-effective low wind speed turbines.

To launch its efforts on developing low wind speed technologies, DOE issued a request for proposals to its industry partners in October 2001. The request provided bidders an opportunity to participate in one of three technical areas: 1) concept and scaling studies, 2) component development, and 3) full-scale prototype turbine development. The first round of this solicitation was conducted in 2002, and several cost-shared contracts were awarded.

The objective of one subcontract awarded to Clipper Windpower Technology, Inc., in November 2002 is to develop a 2.5-MW Quantum prototype turbine with advanced components that will come close to achieving the low wind speed cost goal of $0.03/kWh at Class 4 wind sites. Clipper aims to reduce capital costs through innovative approaches to design and manufacturing processes. Its new design will include an advanced distributed generation drive train with advanced controls and will explore a variable speed rotor for improved performance in low wind speed areas. Clipper will also consider the concept of a self-erecting tower.

GE Wind Energy Energy's 3.6-MW prototype, installed on farmland southeast of Madrid, Spain, represents the most advanced wind energy technology in the world. It is equipped with power electronics and a variable-speed rotor.

Another subcontract currently under negotiation involves GE Wind Energy. Since 1997, DOE has worked with GE Wind Energy and its predecessors to develop advanced utility-scale turbines capable of producing cost-effective electricity in Class 6 wind resource areas. Today, GE Wind Energy is producing hundreds of 1.5-MW turbines at its manufacturing facility in Tehachapi, California, that are descendents of the proof-of-concept turbines developed in partnership with DOE. With the award of the new subcontract, DOE will provide technical support to GE Wind Energy to develop 3.6-MW turbines capable of cost-effective operation in low wind speed areas on-land and offshore.

Supporting Industries

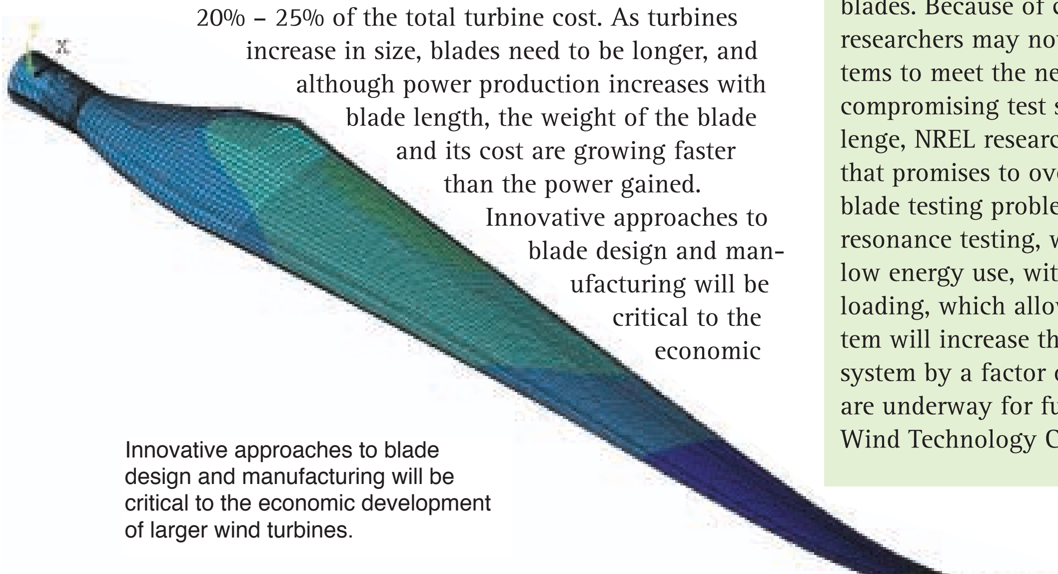
As the turbines grow larger, so must the components that support them. The rotors must be larger with longer blades to capture more energy; the capacity, dimensions,

Turbine research is focusing on the development of multi-megawatt turbines that produce 2 to 3 times the amount of electricity produced by turbines currently in use.

and weight of the drive trains must increase; and the towers must be taller to reach the higher wind speeds in low wind speed areas.

Making Longer, Stronger Blades

The wind turbine rotor, which consists of the blades and the hub, drives the design of the entire wind turbine, because the airfoil and the mechanical properties of the blades determine how much energy is captured and what loads are transmitted to the other turbine components. In addition, blade and rotor manufacturing costs are typically 20% – 25% of the total turbine cost. As turbines increase in size, blades need to be longer, and although power production increases with blade length, the weight of the blade and its cost are growing faster than the power gained. Innovative approaches to blade design and manufacturing will be critical to the economic development of larger wind turbines for low wind speed applications.



Innovative approaches to blade design and manufacturing will be critical to the economic development of larger wind turbines.

The objectives of DOE wind energy research conducted at Sandia National Laboratories are to develop longer, stiffer, thinner blades using innovative blade manufacturing processes that reduce costs, improve quality and reliability, and broaden U.S. blade manufacturing capability. To achieve its objectives, Sandia is working with universities and manufacturers to design and fabricate blades that incorporate advanced materials and aeroelastic designs.

To aid in the design of advanced blades that incorporate innovative materials, Sandia developed a Numerical Manufacturing and Design (NuMAD) software tool that enables designers to model blades in detail and modify and refine material choices using an established materials database. The materials database, also developed and maintained by Sandia working with Montana State University, contains the results of more than 1000 blade material tests to help manufacturers decide which material is best suited to their new design.

Past blade manufacturing techniques were based on fiberglass technology typical of the boat-building industry. Materials that show promise for developing stronger, lighter-weight blades include carbon fiber and carbon/glass hybrid composites. Although carbon fibers are more expensive then the traditional fiberglass materials, they are much stronger and more lightweight and can take higher stress loads to prevent damage to the blades as well as other turbine components. To manufacture

NREL Develops New Blade Test System for Larger Blades

As wind turbines grow larger and their blades longer, researchers will need to find more efficient methods to test the blades for endurance. Conventional tests may not be the best method for testing multimegawatt blades. Because of cost or technical constraints, researchers may not be able to scale up the current systems to meet the needs of the larger blades without compromising test speed or accuracy. To meet this challenge, NREL researchers have developed a new system that promises to overcome some of the multimegawatt blade testing problems. It combines the advantages of resonance testing, which allows full span testing and low energy use, with the advantages of forced hydraulic loading, which allows dual-axis loading. The new system will increase the test speed of the conventional system by a factor of 2. It has been analyzed, and plans are underway for full-scale deployment at the National Wind Technology Center.

As wind turbines grow larger and their blades longer, researchers will need to find more efficient methods to test the blades for endurance. NREL researchers have developed a new system that promises to overcome some of the multimegawatt blade testing problems.

cost-effective blades using carbon fiber composites, researchers are analyzing blade structure and design to gain a better understanding of how loads affect the blades. If they can determine which areas of the blades are subject to extreme loads, and hence damage, they may be able to apply the carbon fiber composites only to those areas to strengthen the blade economically. Two groups are pursuing different paths toward the goal of carbon hybrid blades and blades that twist to reduce loads as they operate. The first team is led by K. Wetzel, Inc., who is working with Wichita State University. The second team consists of Global Energy Concepts (GEC) and TPI Composites, Inc.

To successfully integrate carbon fiber materials, it will be essential to understand how the carbon fiber composites interact with design and other materials. Sandia and Montana State University are also conducting research to characterize carbon capabilities and analyze how they interact with the glass and other materials. Additional materials issues include resins, fiber treatments, and the effect of manufacturing process on material properties.

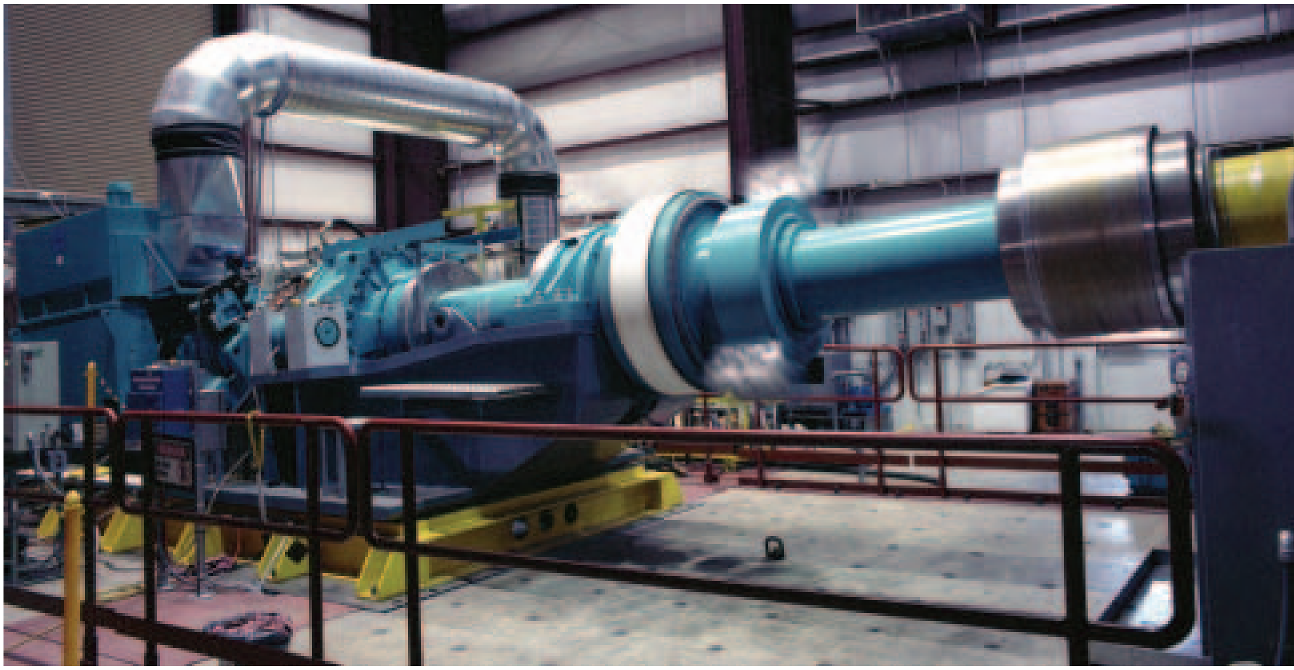
Increasing Drive Train Efficiencies

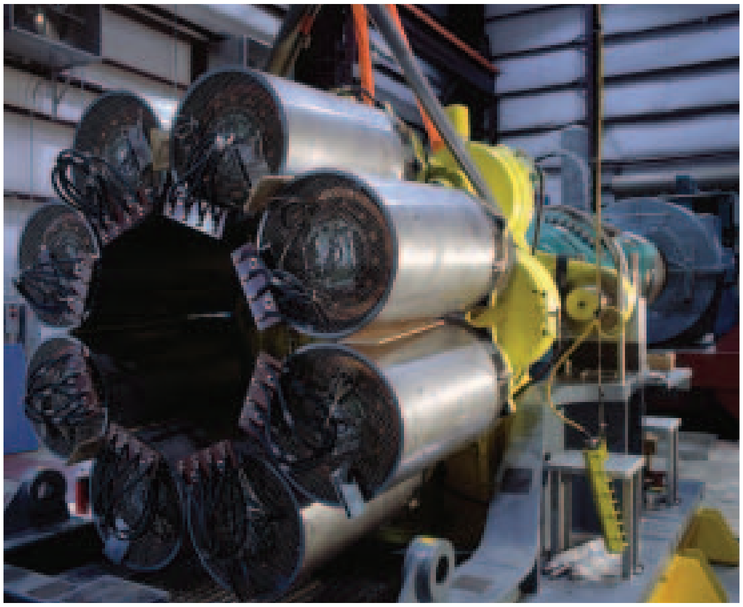
Drive train components, which can include generators, gearboxes, shafts, and bearings, convert the slow-rotating mechanical energy from the rotor into electrical energy. In 2001, GEC and Northern Power Systems began working with DOE to consider different approaches to reducing the costs of drive train components for 1.5-MW turbines. Both companies analyzed cost and efficiency impacts of new approaches to drive shaft supports, gearboxes, gearing configurations, gear loading, gearbox bearings, gearbox supports, generators, generator bearings, and generator supports.

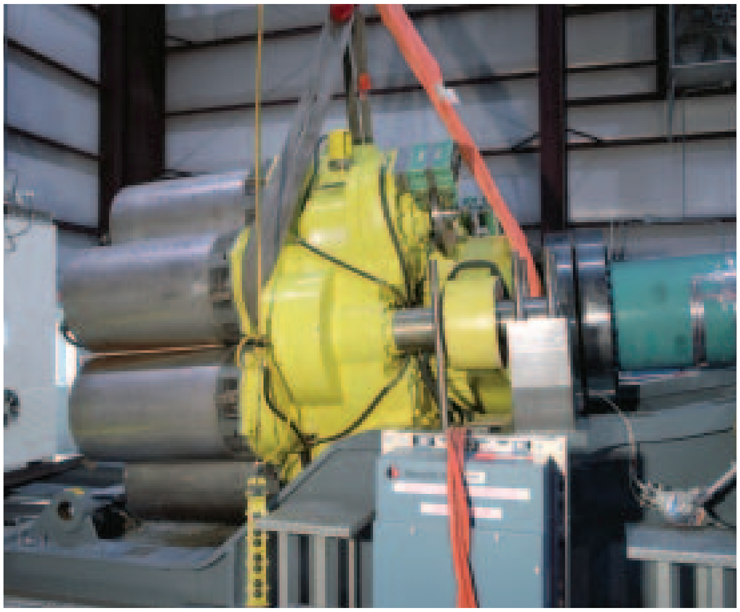
In 2002, GEC finalized a new design for a single-stage permanent magnet (PM) drive train. The preliminary design analysis of this drive train shows high efficiency at low wind speeds, low loss of low input power, and annual energy production estimates that are 3% higher than baseline. Production costs for the single-stage PM drive train are estimated to be 22% less than the baseline drive train, and it shows potential for reducing overall turbine cost of energy (COE) by 10%. GEC began fabrication of the single-stage PM drive train in November 2002 and expects to send a prototype to NREL for testing in September 2003.

Northern Power Systems is focusing its efforts with DOE on the development of a direct-drive PM generator and an accompanying novel power converter that will allow

GE's 1.5-MW drive train undergoes lifetime duration tests at the NWTC.







Clipper Windpower's 1.5–2 MW drive train is being loaded onto the 2.5 MW dynamometer test stand at the NWTC for future testing.

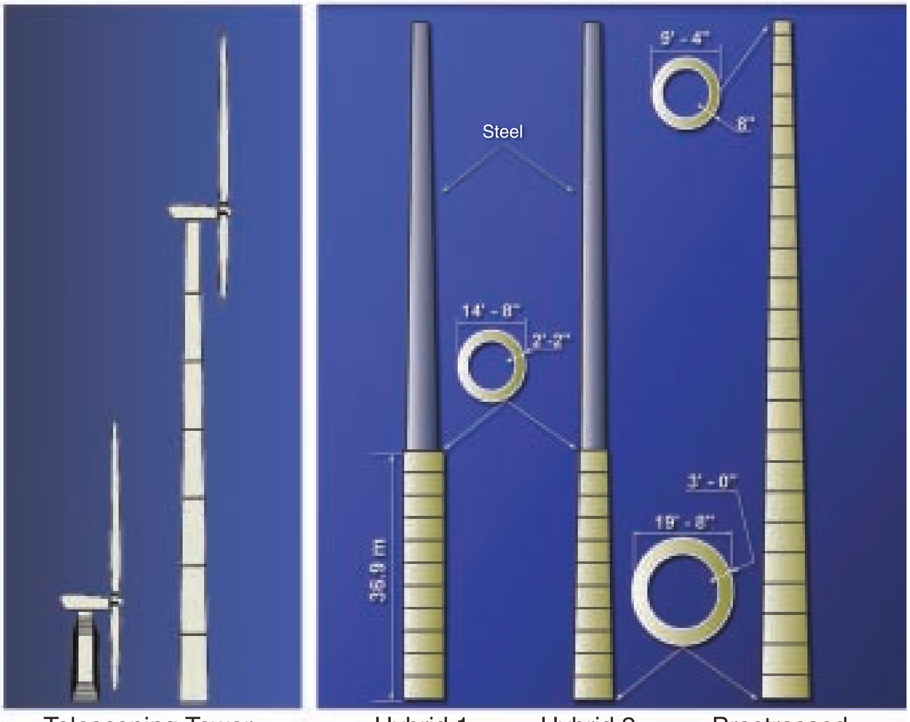
variable speed operation. Preliminary analysis of Northern Power Systems' 1.5-MW drive train design during 2002 showed an significant reduction to cost of operation and maintenance. A drive train prototype will be delivered to NREL in 2003 for testing.

Under its 2002 subcontract with DOE, Clipper Windpower is also developing an advanced distributed generation drive train (DGD) that will provide the benefits of variable speed without increasing the cost from currently utilized approaches. In addition to costing less, the new drive train will be more compact and easier to maintain than comparable commercially available turbines. The preliminary design for the drive train was completed in July 2002, and component orders were sent to the manufacturers. The final DGD, including generators and variable speed control system, will be tested at NREL's dynamometer test facility in the spring of 2003.

Designing Taller Towers

Wind speed increases with height above ground. To reach the higher wind speeds in the low wind speed areas and meet the structural needs of the larger turbines with longer blades, industry must design taller towers. According to a WindPACT study published in 2001, traditional towers taller than 65 m (213 ft) present serious logistics problems during transport and installation. With traditional tapered steel tower designs, the taller the tower, the larger the base diameter. The larger the base diameter, the more difficulties encountered and expenses incurred during transport. One possible solution to the problem of transporting larger tower bases is to construct all or

Advanced Tower Designs



NREL has awarded two research subcontracts to investigate innovative tower concepts that include telescoping towers, steel/concrete hybrid towers, and prestressed concrete towers to reduce installation costs.

part of the tower on site using reinforced concrete. Using concrete rather than steel may also reduce material costs. To evaluate design and construction approaches for economical hybrid steel and concrete wind turbine towers, NREL awarded a subcontract to Berger/Abam Engineers, Inc., in Seattle, Washington, in June 2002. Working with U.S. wind turbine developers, Berger/Abam engineers will target the most cost-effective designs and evaluate the cost viability of using concrete sections for 100-m towers.

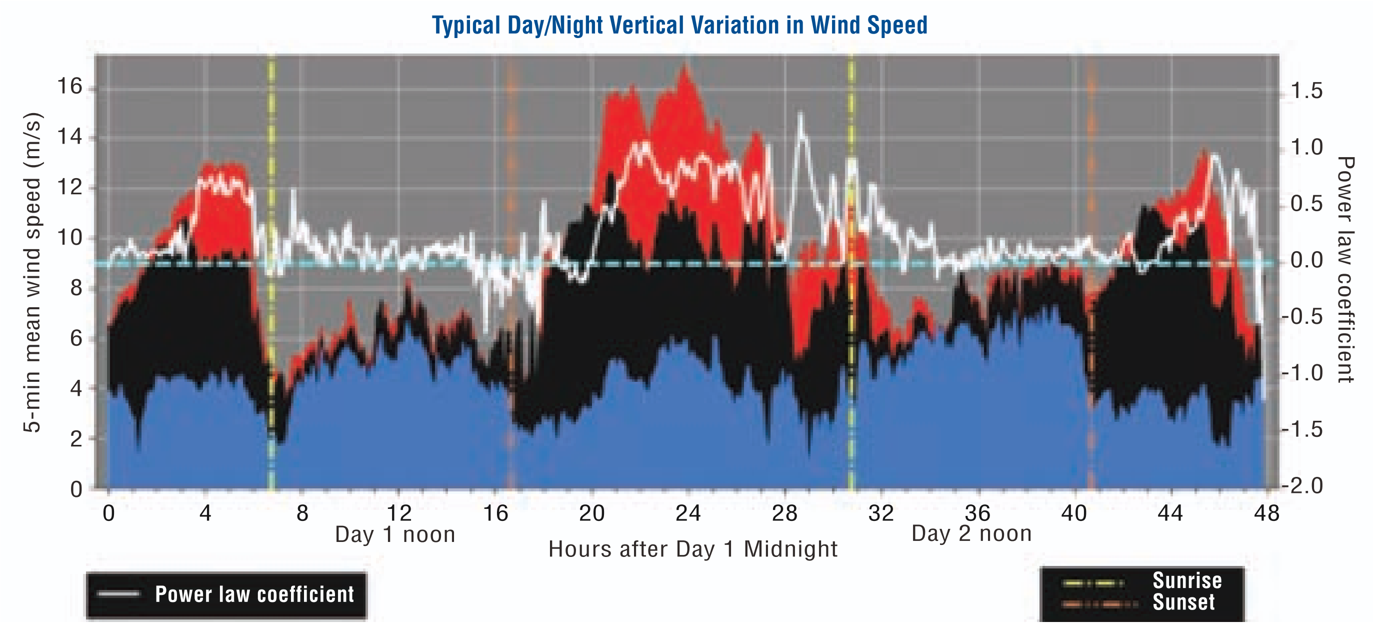
The taller tapered steel towers also require large, expensive cranes for construction and some forms of maintenance and repair. The requirement for such cranes increases the cost of energy from the larger turbines. To eliminate the need for these cranes, NREL researchers are investigating several innovative tower concepts. NREL is negotiating a subcontract to Z-Tek, L.L.C., in Bakersfield, California, for the development of a prototype 100-m telescoping tower. A telescoping tower would eliminate the need for a large crane, thus reducing environmental impacts to the site as well as installation and maintenance time and costs. Telescoping towers would also allow developers to use hard-to-access sites located in rough terrain.

Understanding Turbulent Wind Patterns

Another challenge facing low wind speed turbine developers is the height at which the larger turbines must operate. While wind speeds increase with altitude, so do turbulent wind patterns. Interactions between the turbulent wind patterns and a wind turbine can cause damage that may ultimately limit the turbine's operational lifetime. In the late 1970s and early 1980s, researchers found that multimegawatt turbines experienced larger-than-expected structural loads that contributed to design failures. The structural loads were caused by turbulence encountered at heights that present turbines are now reaching and will exceed as the turbines increase in size and height. To design efficient turbines that can withstand this higher-altitude turbulence, it is critical for researchers to develop accurate simulation models on which they can base their designs.

On the Great Plains, where most of the low wind speed resources are located, wind patterns called nocturnal jets form close to the ground at night. Measurements taken in

To gain a better understanding of the turbulent wind patterns found at higher tower heights, NREL researchers are gathering data from a 120-m tower in southeast Colorado.



Data gathered by NREL researchers verify the existence of turbulent nocturnal jets.

2001 from a 120-m (400-ft) tower located in southeast Colorado, where the nocturnal jets are known to occur on a regular basis, verified that organized turbulent eddies form beneath the jet at heights in which turbine rotors will eventually operate. Current design simulation codes are based on turbulence scaling that is often only applicable at lower elevations. For researchers to develop appropriate design codes, it is critical for them to gain a better understanding of how these turbulent wind patterns and wind turbines interact.

To gain that understanding, Sandia and NREL researchers are gathering data from a 120-m tower in southeast Colorado and from the long-term inflow and structural test (LIST) turbines located on a site near Bushland, Texas and at the NWTC south of Boulder, Colorado. This data will help them characterize the rate of occurrence, magnitude, and sequencing of the entire spectrum of wind events and analyze their impacts on wind turbines. In addition, NREL researchers are using a state-of-the-art Doppler acoustic wind profiler (sodar) and laser wind speed measurement (LIDAR) remote sensing systems to map the vertical and horizontal extent of coherent turbulent wind patterns associated with low-level nocturnal jets above the tower measurements. By combining the data from the tower, turbines, and sensing systems, researchers will be able to expand their design simulation capabilities to include conditions at the heights where the larger wind turbines need to operate reliably.

Distributed Power Applications

Distributed small wind electric systems can also make a significant contribution to our Nation's energy needs. The small wind turbine industry estimates that 60% of the United States has enough wind resources for small turbine use, and 24% of the population lives in rural areas. Using small wind turbines, farmers, ranchers, business owners, and homeowners can reduce their utility bills, stabilize their electricity supplies, displace carbon emissions from conventional fuel sources, and help reduce our dependence on foreign energy supplies.

Using small wind electric systems to provide power for homes and farms is not a new idea. In the 1930s and '40s, thousands of farmers and ranchers used wind systems to charge the batteries that powered their lights, radios, refrigerators, and water pumps. Although today's small wind turbines are much more advanced than the simple battery chargers of the early 20th century, wind energy researchers are working with industry partners to improve designs, increase efficiency, and decrease costs. They accomplish this by carefully reviewing the new designs, testing the prototypes, conducting field verification tests, and developing certification standards. The objective of their research is to provide designers, manufacturers, and those involved in certification with the information they need to better understand small turbine design and operation and how the parameters of the design can affect operation.

This 10-kW Bergey wind turbine on a farm in Webster, New York, helps reduce the farm's utility bill and feeds excess power into the utility grid.

Partnering with Industry to Improve Designs

In 2002, DOE worked with two industry partners to improve small wind turbine designs: Bergey Windpower Company, Inc., in Norman, Oklahoma, and Southwest Windpower in Flagstaff, Arizona. The objective of DOE's work with Bergey Windpower is to develop a highly reliable 50-kW wind turbine for distributed power applications connected to the utility grid. The new turbine will incorporate passive controls (tail and furling) rather than a mechanical brake. On a furling turbine, in high winds the tail stays fixed into the wind and the rotor moves around the tail into a furled or folded position. This reduces the wind that the rotor is exposed to, thus reducing the rotational speed and protecting

Distributed small wind electric systems like this 50-kW turbine can make a significant contribution to our Nation's energy needs.

the variable speed turbine from damage that might be caused by the higher winds. The turbine will also incorporate a new airfoil design for quieter operation, three rotor diameters so that the turbine can be adapted to different wind regimes, and a direct-drive alternator with high-strength rare-earth magnets. Researchers at NREL have tested the new blade design and found that it exceeded minimum requirements for strength by about 75%. Tests on the first prototype will be conducted at the NWTC in 2004.

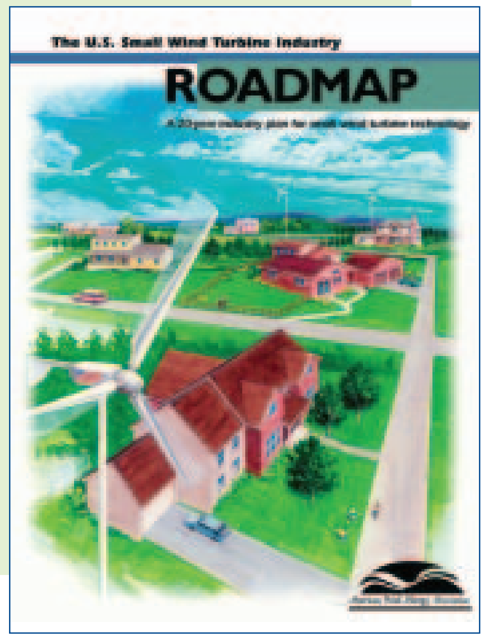
The objective of DOE work with Southwest Windpower is to design a more efficient, more cost-effective small turbine for residential use that can be priced like a home appliance. To keep the cost of the new turbine down, Southwest Windpower will apply lessons learned about low-cost manufacturing from their successful AIR product line. The new turbine can be grid-connected so that its energy production offsets electrical energy consumed in the home. It has an 11-ft (3.4-m) diameter rotor, a peak power output of 1.5 kW, is quiet to operate, and is simple to install. Initial testing of a pre-prototype turbine will be conducted during 2003.

Supporting Research

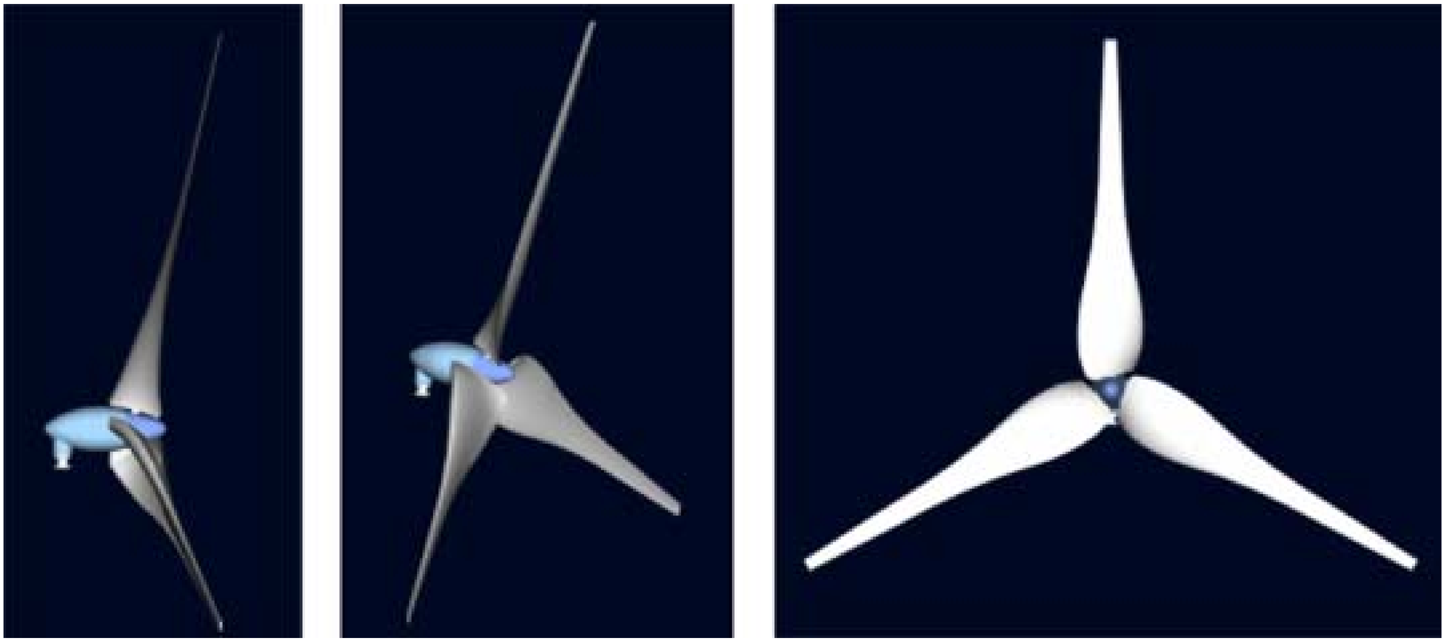
In 2002, researchers at the NWTC began several studies to help small wind manufactures improve turbine and component designs to increase efficiency and reduce noise. One activity, a furling study on a 10-kW Bergey, will provide a better understanding of a wind turbine's furling

The U.S. Small Wind Turbine Industry Roadmap

In June 2002, The U.S. Small Wind Turbine Industry Roadmap, a 20-year industry plan for small wind turbine technology produced by the Small Wind Turbine Committee of the American Wind Energy Association in cooperation with the U.S. Department of Energy was released. The Roadmap identifies barriers to wider use of small wind turbine technology and appropriate near-term, mid-term, and long-term actions to address these barriers. Actions include improving the technology, reducing costs, stimulating the market, and influencing government policies. It also attempts to prioritize these actions and identify priorities for research and development efforts. The roadmap is intended to help guide government and corporate policy toward the overall goal of making small wind a significant contributor to America's domestic energy supply.



In 2002, DOE worked with Bergey Windpower to develop a highly reliable 50-kW wind turbine for distributed power applications connected to the utility grid.



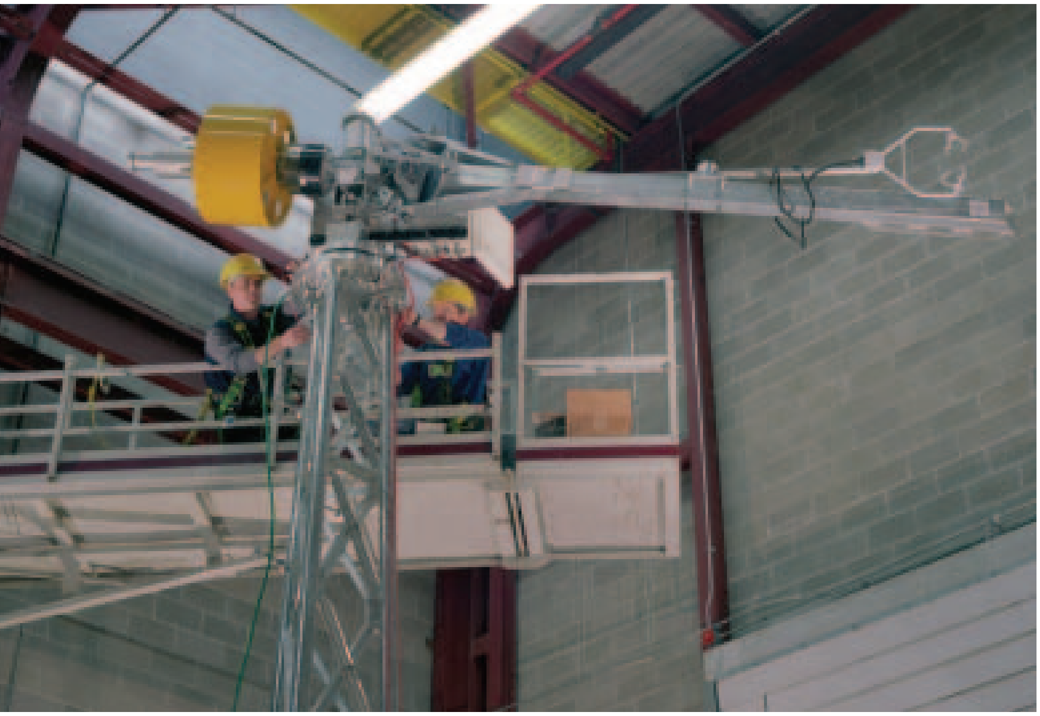
DOE is working with Southwest Windpower to design a more efficient, more cost-effective small turbine for residential use that can be priced like a home appliance.

mechanism. In 1999, NREL conducted a workshop on furling. As a result of that workshop, researchers and manufacturers realized that there are no accurate models of furling small turbines. The study conducted in 2002/2003 will be the first study to provide accurate thrust measurements for a small wind turbine. Accurate thrust measurements are crucial for developing models for furling. With a better understanding of thrust and furling, wind turbine manufacturers will be able to design more efficient turbines more quickly.

In addition to thrust and furling measurements, the turbine will be outfitted with two three-dimensional sonic anemometers that will measure wind speeds upwind and in the tail wake. Measurements of wind speeds in the tail region will help researchers understand the aerodynamic flow around the tail, which will lead to better modeling techniques and algorithms. The turbine will also be tested for tower bending, yaw rate, wake, shaft bending, blade bending, and rotor speed. Testing will begin in 2003.

In another study, researchers from NREL, the University of Illinois in Urbana, Illinois, and the Netherlands National Aerospace Laboratory in Emmeloord, Netherlands, worked together to gain a better understanding of wind turbine aerodynamics and aeroacoustic noise emissions. As the interest in small turbines grows, so does the potential for siting those turbines in residential areas. For small turbines to be readily accepted in the more densely populated areas, it is important for them to operate quietly.

The primary sources of wind turbine noise are inflow turbulence, surface irregularities, trailing edge bluntness, boundary-layer trailing-edge interaction, and the blade-tip vortex. Although progress has been made in predicting noise from these sources,



NREL researchers prepare a 10-kW Bergey wind turbine for a furling study to be conducted at the NWTC.

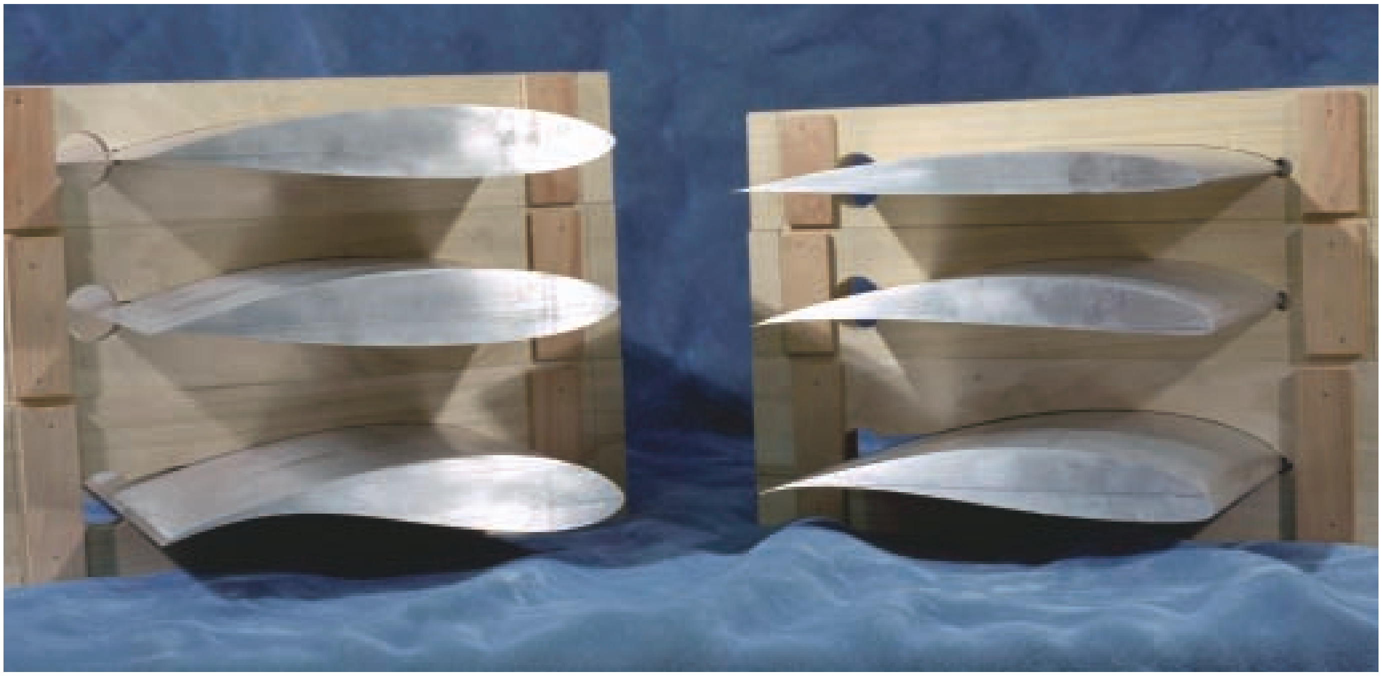
controlling them in a new blade design is still a challenge. To design truly quiet wind turbines, researchers must learn how to reduce the noise produced by trailing edge interaction and the blade-tip vortex.

For their study on aerodynamics and aeroacoustic noise, NREL had six airfoils that are candidates for use on small wind turbines built to precise specifications by Tinel Technologies of Northbrook, Illinois. Two parallel sets of wind tunnel tests were completed using these airfoil models. The models were first sent to the University of Illinois, where researchers completed aerodynamic testing, and then to the Netherlands National Aerospace Laboratory, where aeroacoustic tests were conducted in an open jet anechoic wind tunnel. As a result, NREL obtained high quality aerodynamic and aeroacoustic data for the same airfoils. These data will be published in NREL reports to assist designers of small wind turbines in making trade-offs of energy performance and aeroacoustic emissions.

An NREL researcher conducts an aeroacoustic test in an open jet anechoic wind tunnel at the Netherlands National Aerospace Laboratory.

Verifying Turbine Performance

DOE wind energy researchers also work with industry partners to verify the performance and reliability of small wind turbines up to 100 kW. Under the Small Wind Turbine Field Verification Project, turbine manufacturers can test the performance of their turbines in a range of actual operational applications and environments and publish the results of those tests. In 2002, 12 turbines (Bergey Excel, Whisper H40, and AOC 15/50) were tested under the field verification project at host sites located in Montana, New York, New Jersey, Maine, Rhode Island, and Utah. A duplicate model of each turbine was tested for noise, system safety and function, power performance, and duration according to the standards of the International Electrotechnical Commission (IEC) at the NWTC before the turbines were sent to the host sites. All



NREL contracted with Tinel Technologies of Northbrook, Illinois, to build six candidate airfoils for use on small wind turbines.

This Whisper H40 wind turbine at a host site in Spanish Forks, Utah, is one of the turbines tested under DOE's Field Verification Project.

test results and reports, whether from the host site tests or the NWTC, are available to the general public on the NWTC Field Verification Web site at www.nrel.gov/wind/verification_project.html.

Turbine manufacturers use the test results to adjust their turbine systems and/or the marketing of their products. The results have also been used by wind energy researchers to enhance IEC standards that are presently being written. In particular, the IEC 61400-12 Power Performance Standard was modified to include an annex that discussed testing of off-grid wind turbines. The IEC 61400-2 small wind turbine safety standard used many of the test results to develop an empirically-based approach to design evaluation and loads development.

Setting the Standards

Verifying a turbine's performance by testing it according to IEC standards also helps manufacturers obtain certification for their turbines from accredited agencies. Certification can be an excellent marketing tool that demonstrates to potential investors that the wind turbines comply with internationally recognized standards for safety, quality, and integrity.

The IEC 61400–2 standard for small wind turbines specifies minimum requirements for structural integrity, safety, and other design features in order to ensure safe operation throughout the turbine's intended life. The standard pertains to all subsystems of small wind turbines, including internal electrical systems, mechanical systems, control and protection systems, support structures, foundations, and load interconnection equipment.

In 1999, NREL led an effort to revise the IEC 61400–2 standard initially established in 1995. Members of the IEC maintenance team determined that the standard needed to be revised because 1) it was too narrowly focused and often only vaguely descriptive, 2) its method for obtaining design criteria through the application of simplified load models was not well verified, and 3) safety factors defining design load levels were lumped into uninformative numbers that were confusing and misleading to the users of the standard.

To address these issues and others, the team conducted a study to:

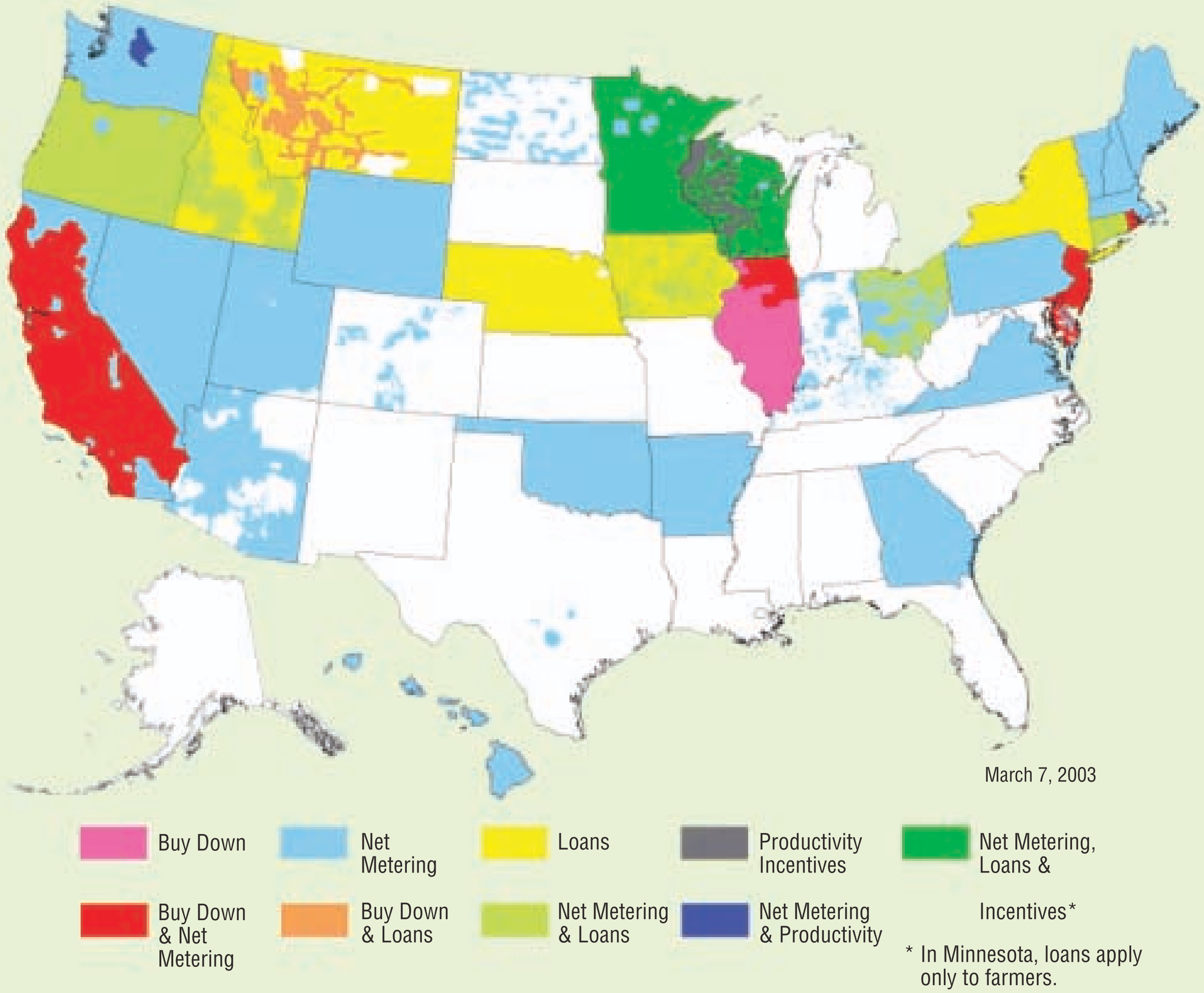
- Identify which extreme loads (both ultimate and fatigue) are not covered by the simplified method
- Assess the range of turbine configurations for which the simplified load method applies
- Establish whether aeroelastic modeling tools can be used to model small, furling turbines
- Quantify the relative magnitude of load safety factors among the various methods.

The draft of the revised standard, completed at the end of 2002, has a higher degree of applicability and dependability than the original. ◆

Small Wind Turbine Development Incentives

Researchers are also providing technical support to states that offer small wind turbine incentives such as buy downs, low-interest loans, productivity incentives, and net metering programs.

Recent net metering legislation in many states requires utilities to buy excess power from small turbines at retail rates. In the volatile energy markets of today and the years to come, such small systems will be a significant part of the energy mix.



Buy downs or Rebates—offer significant reductions of the installed turbine system cost, reducing the initial cash outlay and simple payback periods.

Productivity Incentives—allow for an initial payment based on estimated annual energy production. The payment occurs in the first year and offsets turbine system costs.

Loans—provide consumers access to low-interest rate loans available in many locations.

Net Metering—allows consumers to receive either a credit against future bills, or within a billing cycle, for the excess power they generate. Depending on the net metering policy, the value of the excess kilowatt-hours may have a retail rate or, more typically, an avoided cost or wholesale rate.

Some states offer combinations of incentives to increase the value to the consumer. For the latest information on state-specific small wind incentives check www.dsireusa.org.

Farmers typically receive $2000 to $4000 per turbine per year in land lease payments from wind energy developers.

BRINGING THE TECHNOLOGIES TO MARKET

Wind Powering America

While the U.S. wind energy market has experienced dramatic growth over the past few years, with significant growth in the Northwest, the Great Plains, the Rocky Mountains, Texas, and several eastern states, many states with excellent wind resources remain undeveloped. Most of the undeveloped resources are located in rural areas where farming communities are economically stressed and traditional agricultural incomes are seriously threatened. Wind development in these areas can provide badly needed income to landowners, as well as jobs and tax revenues for local communities. In addition, there are opportunities for wind energy development on Native American lands and through Federal purchases of green power. As the largest institutional load in the world, the Federal government could provide a huge market for green (wind) power, and most of the Native American lands located on 96 million acres, many with excellent wind resources, remain undeveloped.

To increase the use of wind power in these areas, the U.S. Department of Energy (DOE) launched Wind Powering America (WPA) in 1999. WPA is an industry and state-based effort to increase the use of wind energy in the United States over the next two decades.

The goals of the initiative are to:

- Meet 5% of the Nation's energy needs with wind energy by 2020 (i.e., 80,000 MW installed)

- Double the number of states that have more than 20 MW of wind capacity by 2005 and triple it to 24 by 2012
- Support interagency efforts to increase wind's contribution to Federal electricity use to 5% by 2012.

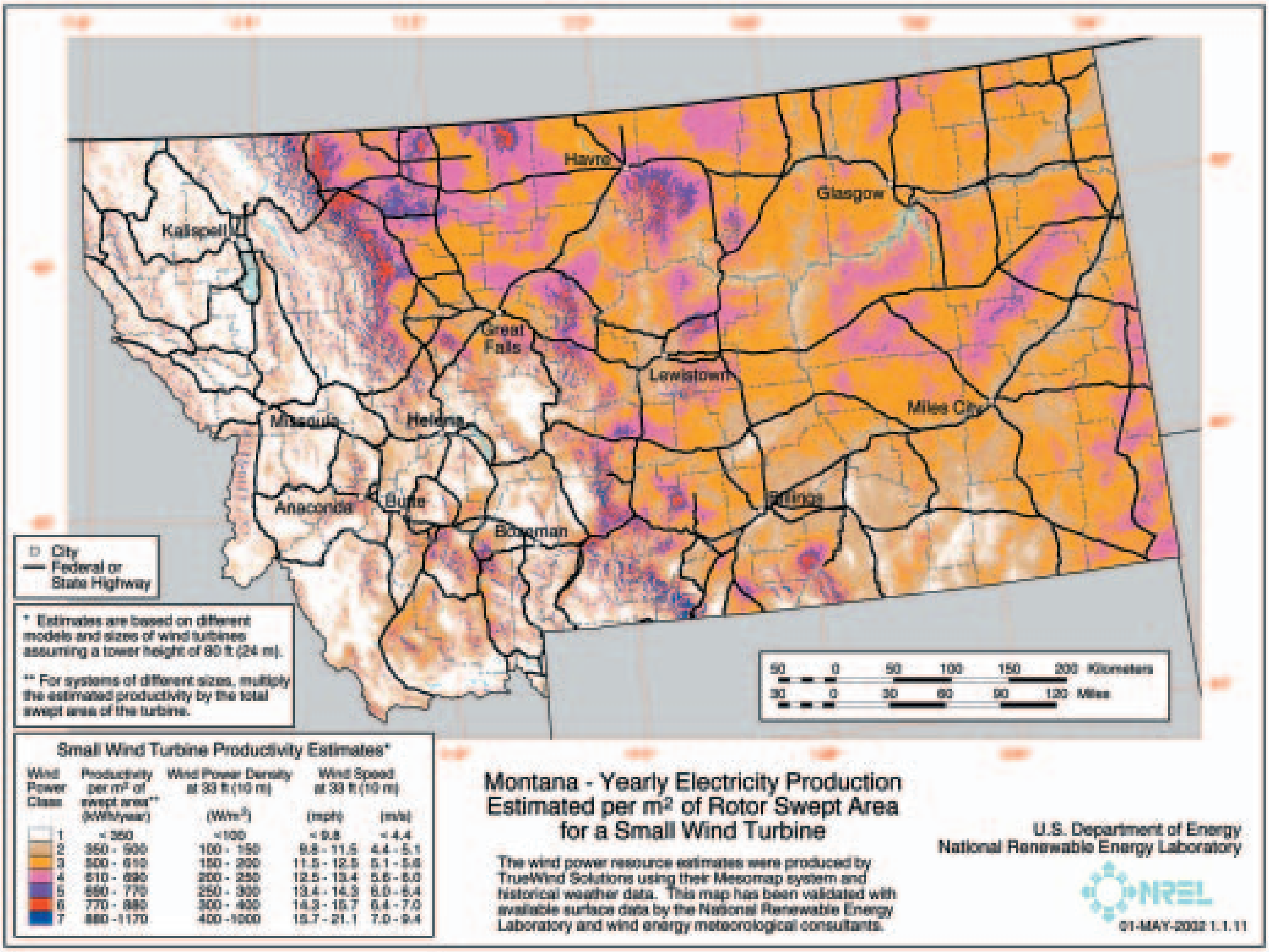
WPA works with Federal agencies, state and local energy offices, Native American agencies, rural agencies and electrical cooperatives, and utilities on: state-based activities, rural economic development, greening Federal loads, and utility partnerships.

State-Based Activities

On the state level, WPA team members develop and provide technical and other types of support, including expert presentations at workshops and community meetings, anemometer loan programs, state wind resource maps, and state-specific small wind consumer guides.

WPA team members conduct workshops and community meetings to educate industry stakeholders and increase public awareness.

The goal of the workshops and community meetings is to educate state audiences about the current state of wind technology, economics, state wind resources, economic development impacts, policy options/issues, and barriers to wind development. State audiences include policy makers, state energy officials, landowners, utilities, advocacy groups, and economic development interests. The key outcome of these meetings is the formation in each state of a wind working group with a set of priority



This Montana wind resource map is an example of the highly detailed regional wind maps analysts are producing as a result of modern mapping systems.

In 2002, WPA team members worked with state energy officials in eight states to customize the Small Wind Electric Systems U.S Consumer's Guide so that it contains a state-specific wind resource map and information about state incentives and state contacts.

activities to move wind development forward in that state. In 2002, WPA supported wind-related events in 14 states and helped to organize 16 wind working groups.

In addition to the state wind working groups, WPA is working with stakeholders to identify the best areas for development, implement anemometer loan programs, and produce highly detailed wind resource maps. In 2002, WPA helped implement anemometer loan programs in 16 states to enable landowners to borrow an anemometer to measure their wind resources for one year without charge. WPA's state partners encourage local universities to administer the programs for educational purposes.

To provide information about wind resources, WPA works with wind resource analysts to update state wind resource maps. Analyzing an area's wind resource is the first step toward both large and small wind system installations. Although developers have relied on the 1987 U.S. Wind Resource Atlas to guide their efforts, modern mapping techniques have enabled analysts to develop more highly detailed wind maps. The new maps have a resolution of one square kilometer, in contrast to the old maps that have a resolution of 25 square kilometers. The new technology also enables analysts to overlay the resource maps to show transmission grids; roads; political boundaries; Federal, state, and Native American lands; and geographical features. In 2002, the team finalized new maps for 13 states: Idaho, Montana, Wyoming, Washington, Oregon, New Jersey, Maryland, Delaware, Pennsylvania, North Carolina, Virginia, West Virginia, and California. The maps are available on the Wind Powering America Web site at www.eere.energy.gov/windpoweringamerica and are also published in the state-specific small wind guides.

DOE published its first small wind guide, Small Wind Electric Systems: A U.S. Consumer's Guide, to answer the many questions generated by a resurging interest in small wind systems. These guides help consumers determine whether it is economically feasible for them to use a wind energy system to provide all or a part of the electricity they need for their homes or businesses. In 2002, WPA team members worked with state energy officials in eight states to customize the U.S. guides to contain a state-specific wind resource map and information about state incentives and contacts. States for which the guides were completed in 2002 include: Idaho, Iowa, Minnesota, Montana, North Dakota, Ohio, Oregon, and Washington.

The WPA team has also worked with DOE Regional Offices, DOE General Accounting Office, and the Environmental Protection Agency (EPA) to promote the use of wind-based supplemental environmental projects (SEPs).

SEPs were designed by EPA to offer emission violators an alternative to paying the standard fines. When a company is found in violation of environmental regulations, the settlement usually takes the form of a fine to the state or Federal government. Under a SEP, the company can volunteer to fund environmentally friendly projects like a wind or other renewable energy projects.

Rural Economic Development

According to the 2002 Federal Farm Bill, farm-based renewable energy generation can become one of America's major "cash crops," improving the livelihoods of farmers, ranchers, and rural landowners across the country. One of the easiest and most attractive ways for farmers and other landowners to benefit from wind power is to allow wind developers to install large wind turbines on their land. Wind projects typically generate an annual payment to the landowner of about \$2000–\$4000 per MW of installed capacity. Given typical wind turbine spacing requirements, a 250-acre farm could increase annual farm income by \$14,000 per year, or more than \$55 per acre. In a good year, that same plot of land might yield \$90 worth of corn, \$40 worth of wheat, and \$5 worth of beef per acre. Because each wind turbine only requires about a quarter of an acre, they do not interfere with normal farm or ranch operations. Therefore, lease payments from wind power provide a stable supplement to a farmer's income, helping to counteract swings in commodity prices. Additionally, local and state taxes and payments in lieu of taxes from wind development provide significant revenue and infrastructure investment for rural communities as well as construction and operation and maintenance jobs.

By sponsoring landowner and community meetings and statewide workshops, WPA communicates the opportunities for wind development to rural communities.

Economic Analysis Tool

In 2002, WPA began working with the National Wind Coordinating Committee's economic development working group to develop a wind project economic analysis tool that can be used to predict whether a project will meet financial objectives. Objectives vary with different types of projects. The objective of an economic analysis of a wind farm is to determine whether the expected energy payments are sufficient to pay the debt on the project and provide an adequate rate of return. A distributed generation project analysis will determine how long it takes energy savings to pay back the initial cost of the system. An analysis of a stand-alone system compares the system cost to the cost of grid extensions.

WPA plans to include a user-friendly economic development spreadsheet on its Web site for interested county and state officials.

Tribal officials see this 750-kW wind turbine installed on the Rosebud Sioux Reservation in south-central South Dakota as the start of economic development that will bring a vital industry to the reservation.

Tribal Wind Power

A special opportunity for economic development also exists for Native Americans. There are more than 700 Native American tribes and Native Alaskan villages and corporations located on 96 million acres in the United States. Many of these tribes and villages have excellent wind resources that could be commercially developed to meet their electricity needs or for electricity export. However, there are several key issues that need to be addressed before wind development on Native American reservations can move forward, including lack of wind resource data, tribal utility policies, sovereignty, perceived developer risk, limited loads, investment capital, technical expertise, and transmission to markets.

To address these issues, WPA conducts Native American workshops where information about the wind development process and available options is provided to Native Americans. In 2002, WPA conducted seven regional workshops for Native Americans and supported the development of an interactive Native American wind interest working group (NAWIG) to exchange experiences, concerns, and information on wind development.

To help address the lack of wind resource data, WPA initiated an anemometer loan project in cooperation with the Western Area Power Administration (WAPA). The anemometer loan project allows Native American tribes to borrow anemometers and the equipment needed for installation to measure the wind resource on tribal lands. Technical assistance is provided for siting, installation, and data analysis. By the end of 2002, 35 anemometers had been installed and eight anemometer projects had been completed.

As a result of the efforts by WPA team members and other supporters as well as financial assistance from DOE and the U.S. Department of Agriculture's Rural Utility Service, in November 2002, work began on the foundation for the first Native American utility-scale turbine project. The 750-kW turbine, installed on the Rosebud Sioux Reservation in south-central South Dakota, will provide power for the Rosebud Casino and Convention Center. Tribal officials see this first turbine as a start of a large multi-tribe economic development initiative that will bring a vital industry to the reservation. Excess generation will be purchased by the Basin Electric Power Cooperative for local use. The tribe has also entered a multi-year agreement to sell green power to Ellsworth Air Force Base, near Rapid City, and is negotiating the first tribal sale of green tags through NativeEnergy.

Greening Federal Loads

As the largest energy user in the world, with an annual consumption of 55 million megawatt-hours, the U.S. Government can provide a huge market for renewable energy. The Department of Defense uses 29 million of those megawatt-hours, or 53% of the Federal electricity budget. A directive issued by the administration in 2000 requires Federal agencies to improve the energy efficiency of their facilities and increase their use of renewable energy.

To achieve an interagency goal to increase Federal electricity use from renewables to 7.5% by 2012 and to help Federal agencies meet the requirements of the directive, WPA is working with the Federal Energy Management Program (FEMP) to help facility managers evaluate their renewable energy options.

One option is to increase their use of renewable energy through the purchase of green power or green tags. Green power is electricity generated by renewable energy technologies like wind power, for which the utility charges a small premium. If green power is not available, agencies can purchase green tags. In a green tag transaction, the agency continues to purchase electricity from its utility and purchases green tags from another supplier, thus supporting and gaining credit for the environmental benefits of renewable energy generation. While barriers to Federal procurement of electricity products with a premium price make it difficult for Federal agencies to purchase electricity generated by renewable energy technologies, the 2000 directive allows the savings generated by energy efficiency measures to be used to offset these premiums.

To help the agencies understand how the procurement process allows for the purchase of green power or green tags, in 2002 WPA and FEMP conducted numerous workshops and meetings for Federal facility managers Nationwide. As a result of those efforts, approximately 18 Federal agencies purchased green power or green tags.

Public Power Partnerships

Regional transmission constraints, operational policies, and a lack of understanding of the impacts of wind energy on utility grids are three of the toughest barriers facing the future development of wind energy. To overcome these barriers and meet its goals of increasing the Nation's wind energy capacity, WPA works with utilities and utility groups like the American Public Power Association (APPA), the National Rural Electric Cooperative Association (NRECA), DOE Power Marketing Administrations (PMAs), the National Wind Coordinating Committee's (NWCC's) transmission working group, and the Utility Wind Interest Group (UWIG).

WPA works with utilities, researchers, the NWCC's transmission working group, and UWIG to identify grid integration issues and analyze transmission constraints. The results of their efforts are then communicated to the public power community through a variety of mechanisms with APPA and NRECA. For example, WPA worked with the NWCC to develop a spreadsheet tool to help utilities analyze the economics of wind. The WPA team also works with utilities and researchers to develop wind power plant analysis models that can be used by utilities to predict the impacts of large wind power plants on their grids. In addition, DOE updated wind resource assessments to help identify the areas best suited to wind energy development. WPA works with PMAs, like the Bonneville Power Administration and WAPA, on analysis, development options, and green tag opportunities.

By working with the utility groups to overcome transmission and operations barriers, WPA will help ensure the continued growth of wind energy in 2003. ◆

The U.S. Navy installed three 225-kW wind turbines on its base on San Clemente Island off the California coast to reduce its use of diesel fuel and the inherent generation of nitrogen-oxide emissions and other pollutants.

EXPLORING NEW MARKETS

In 2001, the National Energy Policy (NEP) called on the Nation to draw on its technological ingenuity and expertise to increase our energy production through research, development, and deployment of domestic, dependable, affordable, and environmentally responsible energy technologies. In response to that call, Energy Secretary Spencer Abraham established three priorities for the Department of Energy:

1. Ensure energy security by strengthening the energy production and delivery infrastructure
2. Focus on programs that increase the supply of domestically produced energy and revolutionize how the country approaches conservation and energy efficiency
3. Direct R&D budgets at ideas and innovations that are relatively immature and ensure the greater application of mature technologies.

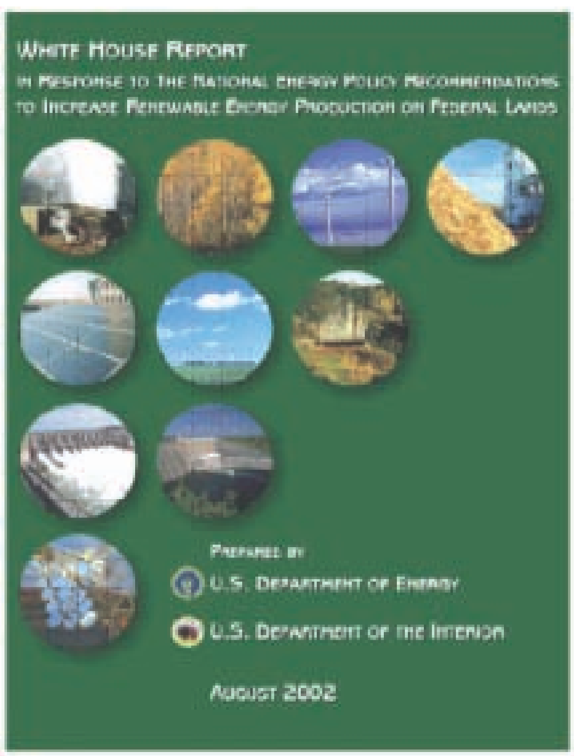
While the DOE Wind and Hydropower Technologies Program is making every effort to answer the call of the National Energy Policy and meet the goals set forth by the Office of Energy Efficiency and Renewable Energy, to meet the wind community's advanced target of 100 GW of wind electric capacity installed in the United States by 2020, it will be necessary to explore new markets and advanced applications for wind energy technologies. Four areas open to future exploration are:

1. Increasing the availability of public lands for renewable energy development
2. Conducting research and development efforts toward offshore wind energy development
3. Investigating the integration of wind and hydropower technologies
4. Exploring the synergy between wind and hydrogen technologies.

Using Federal Lands to Produce Renewable Energy

In response to the directives in the NEP, DOE is collaborating with the U.S. Department of Interior (DOI) to increase renewable energy production on Federal lands. The Federal government controls more than 650 million acres, or about 28%, of the land in the United States. Although some of the land designated for wilderness areas and wildlife refuges may not be available for development, much of the land is located in areas that would be suitable for renewable energy development. In July 2001, DOE and DOI formed an interagency task force composed of representatives from various bureaus within DOE and DOI with participation from the Department of Defense (DoD), Federal Energy Regulatory Commission (FERC), the U.S. Department of Agriculture (USDA), and the Council on Environmental Quality (CEQ). The goal of the task force is to ensure maximum production of renewable energy on public lands. In November 2001, the task force conducted a workshop that was attended by more than 200 senior executives from energy industries and Federal and state agencies. In February 2002, the Bureau of Land Management hosted a follow-up meeting. As a result of the meetings, DOE and DOI compiled a list of 90 suggestions for renewable energy development put forth by the participants and proposed seven actions to aid the progression of renewable energy development. Among those actions is the proposal for an updated version of the U.S. Wind Resource Atlas with a focus on Federal lands.

Ongoing actions that were implemented to promote the use of wind energy from January 2001 through April of 2002 include improving wind resource mapping in states with significant development potential; screening potential locations for wind projects and developing action plans for short-, intermediate-, and long-term development on or near military bases; considering the development of wind projects with North American tribes; and developing education and outreach programs to support the efforts of Federal agencies. As a result, a report was submitted to the White House in August 2002 that detailed activities completed, underway, and planned across agencies to promote development of renewable resources on Federal lands. Actions completed for wind energy development include the installation of 1,800 kW of wind generation by the Department of Defense at three military facilities and the installation of anemometers to collect wind data at Federal and tribal sites in Antarctica, California, Colorado, Oklahoma, Nevada, and Washington.

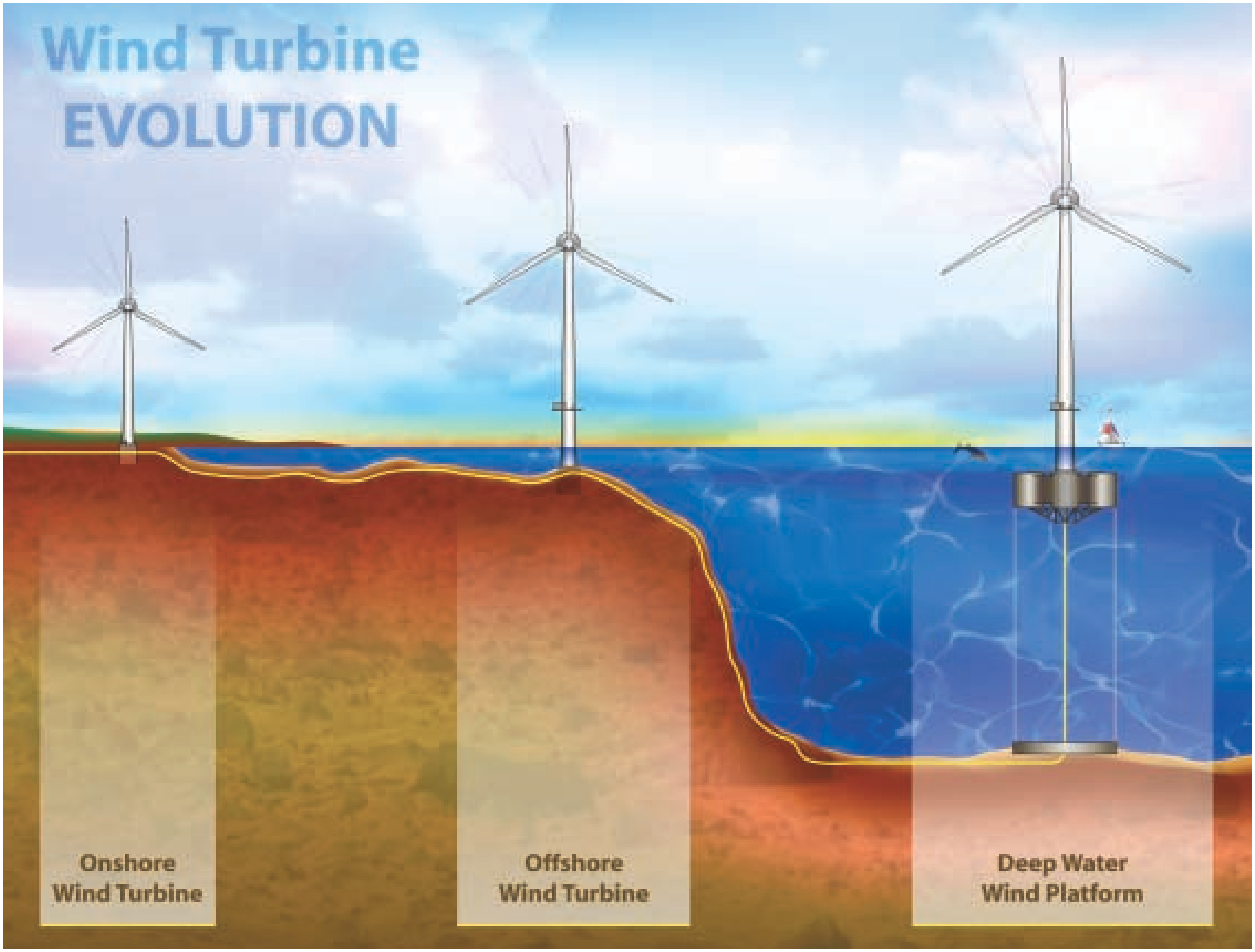


Developing Offshore Resources

Another goal of the DOE Wind and Hydropower Technologies Program is to expand the potential for offshore wind resource development. The current projects on the east coast—Cape Wind and the Long Island Power Authority—have sparked greater interest and media attention on the offshore markets. As a result, some stakeholders are looking to the Federal government for guidance and information. Until now, the U.S. wind industry has not focused on the offshore market because there is still tremendous potential on land, and offshore power generation is more expensive. In the northeastern coastal regions, however, there appears to be a different set of motivations for development offshore. These incentives include coastal markets with tremendous transmission constraints, increasing costs of electricity, and evidence of high potential wind classes offshore. This set of criteria may well be applicable to other coastal regions and the Great Lakes.

The Europeans have been funding demonstration projects for more than 10 years, but the total installed power is only about 260 MW (all in the North European seas). Most recently, the Horns Rev project, off the coast of Demark, will be the largest installation with 80 turbines and 160 MW. Overall, the European offshore activities have been limited and close to shore. There are some strategic planning activities that may change the landscape of offshore development within the U.K. and Ireland in the next several years. For example, the Irish government has given planning authorization for a 200 turbine wind farm at Arklow Banks in the southeast part of the country. In addition, other European nations with significant onshore developments will be looking toward deep water for the next generation of projects, e.g., Germany.

DOE is committed to tracking domestic and international activities and is beginning to assess the potential for offshore wind developments in the United States. There are several primary areas that require further exploration, including assessing the resources (mapping), estimating the costs, and evaluating the technical, legal, and environmental challenges. There are ongoing discussions focusing on how and to what extent the Program will explore the offshore potential as a strategic goal for significantly expanding wind resource projects along our coasts. Wind energy researchers are evaluating analyses, research



DOE's Wind Energy Program is assessing the potential for offshore wind energy development for both shallow and deep water locations.

and development, and outreach efforts needed to investigate, prove, and promote offshore wind development opportunities.

This fiscal year the wind energy research, through NREL, will focus on several activity areas.

Offshore Technology Development:

- The Phase II, low wind speed turbine solicitation was expanded to include offshore concepts, components and full systems.
- The appropriate goal for offshore cost of energy is under consideration.

Wind Resource Mapping Plan:

- A coastal region mapping plan will be developed with mesoscale models.
- The series of maps will indicate offshore wind resources in six areas with priority regions identified.
- Schedule and deliverables will be prepared this year.

Tracking Projects and Studies in Europe:

- Status and size of European projects will be studied.
- Findings from marine and avian studies that may assist our domestic environmental research concerns, e.g., methodological approaches will be analyzed.
- Program representatives will attend relevant conferences and continue their participation in the International Standards Organization, International Energy Agency, and the International Electrotechnical Commission (e.g., drafting design requirements for offshore wind turbines).

Organizing a Workshop for Federal Agencies:

- The workshop will be scheduled for summer 2003.
- The workshop's agenda will consider the implications of proposed new Congressional legislation that would change the oversight of non-extractive energy projects in the Outer Continental Shelf (considering the Department of Interior or the Department of Commerce),

insights on the permitting process, and identifying barriers and opportunities for offshore projects.

Organizing a Strategic Workshop on Deep Water Technologies:

- The workshop will be scheduled for fall 2003.
- International participation will be encouraged.
- Engineering challenges and topics for further research, such as cost-effective anchoring and installation, structural dynamics, platform dynamic stability, operation and maintenance requirements, and cables and transmission will be identified.

Integrating Wind and Hydropower Technologies

While fluctuating power levels and transmission constraints have hampered ready adoption of wind energy to the utility grids, fluctuating water levels, growing pressures on water supplies, the need for flood controls, and environmental issues are just a few of the constraints that may limit the future growth of hydroelectric production. The U.S. Department of Energy has started a research project to examine whether wind and hydropower technologies can work together to provide a stable supply of electricity to an interconnected grid. While researchers theorize that hydropower facilities may be able to act as a “battery” for wind power by storing water during high-wind periods and increasing output during low- or no-wind periods, a detailed analysis examining regulation, load following, reserve, and generator and grid operations has not been performed.

To gain a better understanding of the synergy that may exist between wind and hydropower technologies, DOE researchers are working with Federal agencies such as the Bonneville Power Administration, the Western Area Power Authority, and the Tennessee Valley Authority to analyze potential and existing generation projects and watershed basin and electric control areas. One of the key questions they will try to answer is: Can hydro operations be modified to accommodate wind without adversely affecting the other flow requirements? They will also attempt to quantify the benefits of integrating wind and hydropower systems.

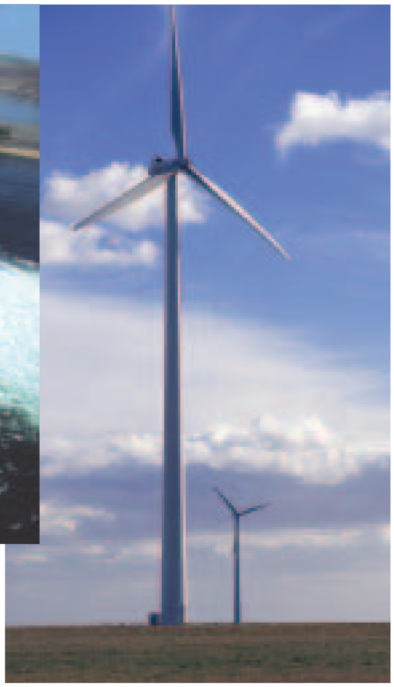
Exploring the Wind and Hydrogen Synergy

Wind energy can be harnessed to provide electricity at some of the lowest costs available for new generation. Coupling wind turbines to hydrogen-generating electrolyzers has the potential to provide low-cost, environmentally-friendly distributed generation of hydrogen in addition to electricity. In this way, hydrogen generation can be a pathway for wind generation to contribute directly to reducing the Nation’s reliance on imported fuels.

DOE researchers are investigating key technical and market issues in an effort to explore this wind and hydrogen synergy, specifically:

1. What regions in the United States have the greatest potential for employing wind turbines to produce both electricity and hydrogen, and under what conditions and time frame are they likely to become economical?
2. What are the costs of wind systems that produce both electricity and hydrogen, both today and in the future?
3. What are the opportunities for reducing system cost, by designing hybrid wind-based systems specifically for production of electricity and hydrogen?
4. What areas should research focus on to have the greatest impacts on cost, both in the near- and long-term?

DOE wind energy researchers are developing a modeling framework to identify promising development areas and better define costs, to provide a systematic summary of the potential for co-producing hydrogen fuel and electricity. ◆



DOE has started a research project to examine whether wind and hydropower technologies can work together to provide a stable supply of electricity to an interconnected grid.

National Wind Technology Center near Boulder, Colorado.

Sandia National Laboratories in Albuquerque, New Mexico

DOE WIND ENERGY RESEARCH

The success of the U.S. Department of Energy (DOE) Wind and Hydropower Technologies Program can be measured by the decreased cost of generation (more than 80% in the past 20 years) and the increased use of wind energy. Wind energy has become the fastest growing form of energy generation in the world. The program's success can be attributed to effective cost-shared public-private partnerships with industry and stakeholder organizations.

The mission of DOE wind energy research established by the Office of Energy Efficiency and Renewable Energy (EERE) is to:

"Conduct research and development to advance wind turbine designs that can operate economically in lower wind resource areas and to develop more environmentally friendly technologies to maintain the Nation's existing hydropower capacity."

To advance EERE's mission, two of DOE's principal research laboratories, the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (Sandia), work side-by-side with private industry partners and researchers from universities nationwide to develop advanced wind energy technologies.

Each laboratory is extensively equipped with a unique set of skills and capabilities to meet industry needs. NREL's National Wind Technology Center (NWTC) near Boulder, Colorado, is designated as the lead research facility for wind research. The NWTC conducts research and provides its industry partners with support in aerodynamics, structural testing, field testing, structural code development, controls theory and control systems, systems analysis, power system analysis, certification, and subcontract management. Sandia, based in Albuquerque, New Mexico, conducts research in advanced manufacturing, component reliability, aerodynamics, structural analysis, material fatigue, and control systems.

Wind energy research conducted by the two laboratories falls under one of three categories: (1) applied research, (2) turbine research, and (3) cooperative research.

Applied Research

The major aim of applied research is to develop advanced low wind speed turbines capable of further reducing the cost of wind energy. Understanding the natural and mechanical factors at work in wind energy generation is crucial to developing more efficient turbines that can produce electricity at lower cost.

Inflow and Wind Characteristics

Multimegawatt advanced low wind speed turbines must operate on very tall towers to take advantage of the increased wind speeds at higher altitudes. On the Great Plains, where most of the low wind speed resources are located, wind patterns called nocturnal jets form closer to the ground at night. Very little is known about these turbulent wind patterns. Interactions between turbulent wind patterns and a wind turbine can cause damage to the rotor that will ultimately limit the turbine's energy capture and operational lifetime. To design efficient turbines that can withstand this higher altitude turbulence, it is critical for researchers to develop accurate simulation models on which they can base their designs. For researchers to develop appropriate design codes, it is critical for them to gain a better understanding of how these turbulent wind patterns and wind turbines interact.

To gain that understanding, DOE is conducting research on inflow and wind characteristics. Conducted by researchers at NREL and Sandia, this research has two major components: 1) performing the field research and developing the characterization tools necessary to quantify the physical properties of the inflow, and 2) developing models and expertise necessary to validate wind resources.

Researchers are working to isolate the source of modeling uncertainties in current codes and develop methods for improving

Aerodynamics

Because low wind speed turbines will be larger and lighter weight than previous models, they may be more vulnerable to material fatigue, and it is difficult to predict how these turbines will interact with the turbulent wind patterns in which they must operate. To gain a better understanding of wind turbine aerodynamics, researchers at NREL and Sandia are combining two-dimensional field and wind tunnel test data to predict aerodynamic loads on turbines under varied inflow conditions. To improve the predictive power of these analyses, researchers are adapting a more accurate approach used for helicopter and aircraft design. Their evaluation will be based on analyses of three-dimensional computations of fluid dynamics. Work is also underway to develop an airfoil that produces little noise.

Systems and Controls

To further reduce the cost of wind energy and advance low wind speed technologies, researchers are looking for ways to develop new, more efficient turbine components and innovative component control systems that are fatigue resistant for minimal cost. The control strategies must increase energy capture and reduce structural loading. To achieve these goals, researchers are studying conventional turbine component controls such as blade pitching, new components such as twist-coupled blades, and advanced devices such as micro-tabs.

The new control systems are tested at the NWTC on a 600-kW controls advanced research turbine (CART). Blade motion, pitch positioning, and rotor speed can be independently controlled on the CART.

At Sandia, work is underway to develop aeroelastic tailoring control systems, in which blades are designed with bend-twist coupling that promotes pitch-to-feather motion, to reduce material fatigue.

Materials, Manufacturing, and Fatigue

To meet the low wind speed goals, researchers will need to design larger rotors with longer blades to sweep greater areas for improved energy capture. Stronger, lighter-weight materials and improved blade designs will be needed to keep the cost of the larger rotors at a minimum. Researchers at Sandia develop tools to better predict how materials and component parts of turbines react to high loads, especially from infrequent high wind gusts. The performance of composite materials, especially resin systems and carbon and carbon/glass hybrids, is a special focus of this research. Nondestructive testing techniques of materials are being developed at Sandia, which maintains a test site for wind turbine components at the U.S. Department of Agriculture's Agricultural Research Service in Bushland, Texas. Sandia's researchers also investigate ways to reduce the cost of the manufacture of turbines, especially rotor blades.

Design Codes

The cost of developing advanced low wind speed turbines can be further reduced if researchers can accurately predict their performance and loads before they are built. To accurately predict the behavior of new design concepts, designers must have accurate design codes to produce realistic models that simulate the behavior of a wind turbine in complex environments – storm winds, waves offshore, earthquake loading, and extreme turbulence.

Current simulation codes developed over the past 10 years can model the effects of turbulent inflow, unsteady aerodynamic forces, structural dynamics, drive train response, and control systems. To further reduce the cost and risk of production to manufacturers, researchers have established a short-term goal of increasing code accuracy and reducing modeling uncertainty. Researchers are working to isolate the source of modeling uncertainties in current codes and develop methods for improving the accuracy through code validation and model tuning. For future advanced design concepts, researchers have set a long-term goal of predicting turbine response and loads to within 15% accuracy.

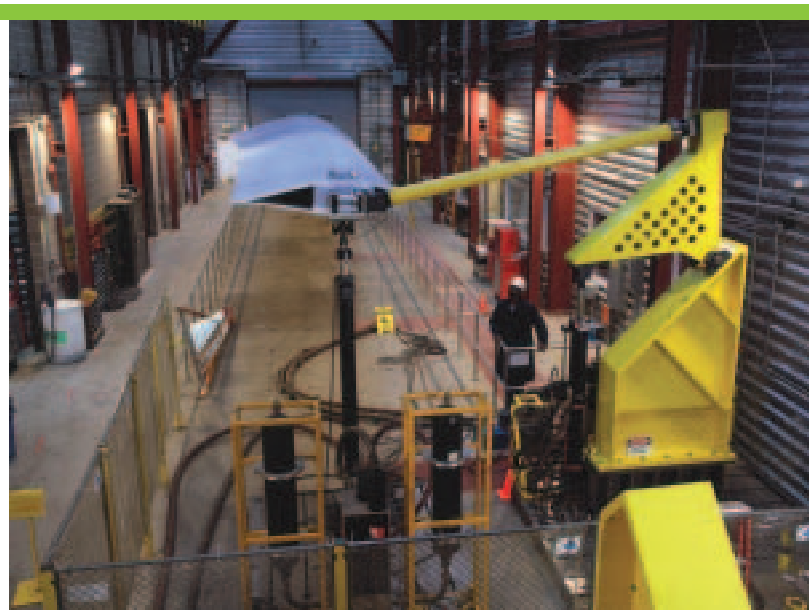
University Research

To increase the base of scientific and technical knowledge of wind energy and develop centers of wind energy research excellence, DOE forms partnerships with universities and educational institutions nationwide. NREL and Sandia support this effort by awarding multi-year university research subcontracts in areas of special interest and value to wind energy research. Partnering with universities also enhances graduate research training opportunities to develop highly qualified scientific and engineering personnel to meet future National needs in wind and other energy fields. Several university subcontracts were awarded in 2002 under a broad-based university solicitation. Areas in which the universities will support wind energy research in 2003 include:

- Advanced aerodynamics codes
- Advanced aero-turbulence codes development
- Studies in composites, material reliability, and strength
- Blade conceptual design, innovation, evaluation, and testing
- Research in innovative generators and power electronics.

Turbine Research

To meet the DOE goal of developing advanced wind turbine designs that can operate economically in lower wind resource areas, researchers at NREL and Sandia are working with industry partners to research, design, build, test, and refine advanced large and small wind turbine designs.



Researchers at the NWTC conduct structural tests on full-scale wind turbine blades for wind energy program subcontractors and NREL's wind industry partners.

These public-private partnerships are developing breakthrough technologies that will significantly reduce the cost of wind-generated electricity and, ultimately, expand our domestic renewable energy supply.

Wind turbine research is focused in two areas. The first area, development subcontracts, provides yearly funds and project management to support competitively selected industry partners in their development of advanced technologies. The second area, supporting research and testing, provides a wide range of technical support, design review, and testing for industry partners.

Development Subcontracts

Through Sandia and NREL, the DOE Wind and Hydropower Technologies Program provides funds and project management to competitively selected industry projects developing high-risk, advanced wind technology. Researchers working under these contracts explore the effects of increased turbine size on performance and cost.

Low Wind Speed Turbines

Low wind speed turbine research will be conducted under public/private partnerships formed through the award of cost-shared technology development subcontracts. These subcontracts assist U.S. industry in developing advanced cost-effective low wind speed turbines and components that can contribute to achieving the program objective. A broad-based solicitation for subcontracts was issued in FY 2002 for three technical areas: 1) concept and scaling studies, 2) component development, and 3) full-scale prototype turbine development. The award of six subcontracts is underway. A second round of solicitations is expected to begin during FY 2003 with awards and funding beginning in FY 2004. The goal of the low wind speed turbine research is to reduce the cost of energy from large wind systems to 3¢/kWh in Class 6 (6.7 m/s measured at a height of 10 m) wind resources by 2004, and to 3¢/kWh in Class 4 (5.8 m/s at a height of 10 m) wind resources by 2012 (compared to a 2002 baseline of 4¢/kWh in Class 6 and 5.5¢/kWh in Class 4).

Distributed Small Turbines

Small wind turbines can be combined with solar electric systems, diesel generators, micro gas turbines, and batteries to form powerful hybrid systems capable of powering ranches or small villages. These hybrid systems have great potential in the developing world market, as well as in rural areas of the United States. Small wind turbines can also be connected to the utility grid by consumers to help offset their utility bills. DOE, NREL, and Sandia are collaborating with the wind industry and utilities to develop and test small turbines for specific applications. The goal of the distributed small wind turbine research is to reduce the cost of energy from small wind turbines (100 kW or less) to achieve $0.10 to $0.15 /kWh in Class 3 (5.3 m/s at 10 m) wind resources by 2007 (previous research focused on Class 5 [6.2 m/s at 10 m] wind resource areas).

Supporting Research and Testing

DOE wind energy research supports its industry partners as well as a wider range of subcontractors by providing design review and analysis, field-testing, structural testing, and dynamometer testing.

Design Review and Analysis

NREL and Sandia evaluate the adequacy and safety of engineering designs explored in each subcontract, offering a wide range of tools to help companies solve problems and meet project deadlines. The laboratories collaborate with Underwriters Laboratories (UL) on design review and testing for UL certification of wind turbines and wind turbine components for large and small turbines.

Field-Testing

Field-testing provides high-quality testing of whole turbine systems installed in the field and provides insight into performance under actual conditions. In 2001, NREL's NWTC was accredited to perform field tests of power performance, noise, loads, and power quality in turbines, and it is helping to develop international standards for field-testing.

Structural Testing

Researchers at the NWTC structural test facility conduct structural tests on full-scale wind turbine blades for program subcontractors and NREL's wind industry partners. The structural test facility's capabilities include fatigue testing, ultimate static strength testing, and several nondestructive techniques, such as photo-elastic stress visualization, thermographic stress visualization, and acoustic emissions.

Dynamometer Testing

NREL's 2.5-MW dynamometer is used to conduct a range of wind industry system tests that cannot be duplicated in the field. The NWTC staff conducts tests on the

DOE, NREL, and Sandia are collaborating with the wind industry and utilities to develop and test small turbines for specific applications.

dynamometer, including gearbox fatigue, wind turbine control simulations, transient operation, and generator and power system component efficiency and performance. Before NREL's dynamometer facility was completed in 1999, the only way to verify operating integrity was to test a field prototype under severe conditions. The facility provides improved methods for full-system testing of wind turbine systems to identify critical integration issues before field deployment. The facility gives the U.S. industry an edge over strong European competition because it is the only facility of its kind in the world.

Cooperative Research

The wind energy cooperative research projects are designed to develop new markets, with emphasis on rural development, integrating wind with other energy sources, penetrating low-wind regions, and promoting National and regional policies that encourage use of wind energy. Cooperative research promotes strong partnerships with a variety of stakeholders, including industry, utilities, government (Federal, state, and local), regulatory bodies, power marketers, environmentalists, public interest groups, and private sector elements.

Wind Powering America

DOE's Wind Powering America (WPA) is a regional and state-based commitment to increase the Nation's use of wind energy technologies, including low wind speed technology, to increase rural economic development, enhance our domestic energy supply, and enhance the Nation's energy security. WPA's goals include meeting 5% of our electricity needs with wind power by the year 2020, tripling the number of states with significant wind power capacity, and increasing the Federal government's use of wind and other renewable energy to 7.5% by 2012. To achieve these goals, WPA provides technical support and outreach about all aspects of utility-scale development and small wind electric systems to utilities, rural cooperatives, Federal property managers, rural landowners, Native Americans, and the general public.

Wind Resource Assessment

One of the first steps to developing a wind energy project is assessing the area's wind resources. Correct estimation of the energy available in the wind can make or break the economics of a wind project. To provide the best information possible, wind energy researchers have developed a computerized mapping system that produces new high-resolution wind maps. The new maps have a resolution of 1 square kilometer in contrast to the old maps that have a resolution of 25 square kilometers. Using Geographic Information Systems, researchers can add overlays of significant features, such as power lines, park boundaries, and roads to the wind resource maps. In 2002, NREL researchers began a multi-year effort to update the U.S. Wind Resource Atlas produced in 1987 based on the new mapping techniques.

Industry Support

The wind energy research conducted by DOE supports industry and Federal and state agencies through the publication and distribution of information concerning the development and potential deployment of wind energy technology. Publications range from highly technical reports targeting the engineering community to outreach publications geared for general public audiences. DOE also supports organizations such as the National Wind Coordinating Committee and Utility Wind Interest Group. Both organizations are run by industry, and they strive to help utilities and public organizations gain a better understanding of the value of wind energy and the barriers to deployment. The wind resource assessment efforts also contribute to industry support.

Regional Field Verification

DOE wind energy researchers work closely with industry partners to research, develop, and verify advanced large and small wind turbine systems. These public-private partnerships include cost-shared research that leads to the development of prototype advanced wind turbines and field verification projects that prove the operational performance of prototype wind turbines in a commercial environment.

The objectives of the Regional Field Verification Project are to:

- Support industry needs for gaining initial field operation experience with advanced technology wind turbines and verify the performance, reliability, maintainability, and cost of new wind turbines in a commercial environment
- Help expand opportunities for wind energy in new regions of the United States by tailoring projects to meet unique regional requirements
- Document and communicate the experience from these projects for the benefit of others in the wind power development community.

Wind Integration

As the need to stabilize our energy resources and electricity demands increase, more utilities are seriously evaluating wind power to provide a portion of their generation mix. At the same time, many utilities are expressing concerns of possible impacts on system operations when greater percentages of wind power are introduced into the electric power system. Their concerns, if not adequately addressed, could significantly limit the development potential of wind power in this country.

Wind energy researchers are assisting industry partners with a number of projects aimed at increasing utility understanding of integration issues and confidence in the reliability of new wind turbine products. Information gained from the projects will be distributed through a National outreach effort to investor-owned utilities, electric cooperatives, public power organizations, and energy regulators to encourage the inclusion of wind power in generation portfolios and ensure the continued growth of the wind energy industry.

Certification and Standards

International certification standards ensure that wind turbine designs are sound, safe, and constructed with good engineering practice. The sales of U.S. wind turbines abroad depend heavily on their ability to meet international wind energy standards. Prior to 2000, members of U.S. industry were forced to go to Europe for all of their certification design evaluations and final certification approvals. In 2000, NREL completed a certification quality system that supports design evaluation and certification approval through a partnership between Underwriters Laboratory (UL) and the certification team at the NWTC. Standards developed under the International Electrotechnical Commission (IEC) are used as the basis for this certification program. However, new standards are under development that will update or create new technical requirements and design techniques. These new techniques will be driven by European experience unless NREL undertakes investigations into new design techniques. Research must be conducted to support the standards development or the U.S. manufacturers will be forced to design according to European rules. Industry participation in the standards process is critical to ensure U.S. experience is included in these standards. Researchers at NREL and Sandia serve on international standards committees, and NREL acts as the certification agency for the United States. ◆

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our Nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our National energy infrastructure
- Facilitate the emergence of hydrogen technologies as a vital new "energy carrier."

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Wind Energy Program Web Sites:
U.S. Department of Energy:
www.eere.energy.gov/wind
National Renewable Energy Laboratory:
www.nrel.gov/wind
Sandia National Laboratories:
www.sandia.gov/Renewable–Energy/wind–energy/homepage.html
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